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747.

Vol. XXXIII.—April, 1895.

A LINE OF 28-IN. CAST-IRON SUBMERGED PIPES ACROSS THE WILLAMETTE RIVER, AT PORTLAND, ORE.

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READ MARCH 6TH, 1895.

WITH DISCUSSION.

The line of submerged pipes, forming the subject of this paper, is a portion of the main pipe line constructed during 1893 and 1894 to supply the city of Portland with pure water diverted from Bull Run, a mountain stream about 30 miles distant.

With the exception of the submerged section, the portion inside the city limits (about 6 miles), connecting the high-service reservoir on the east side of the Willamette River with the high-service reservoir on the west side, consists of cast-iron pipes 32 ins. in diameter.

Proposals were received for this work three times before the contract was finally awarded. On March 1st, 1893, bids were opened for two lines of 24-in. cast-iron pipes. All bids were rejected, and it was not

until August 15th of the same year that bids were again received; this time for a single line of 28-in. pipes. The specification set forth that bids would be received for both cast-iron pipes and riveted pipes of wrought iron or steel. Each bidder was required to submit with his

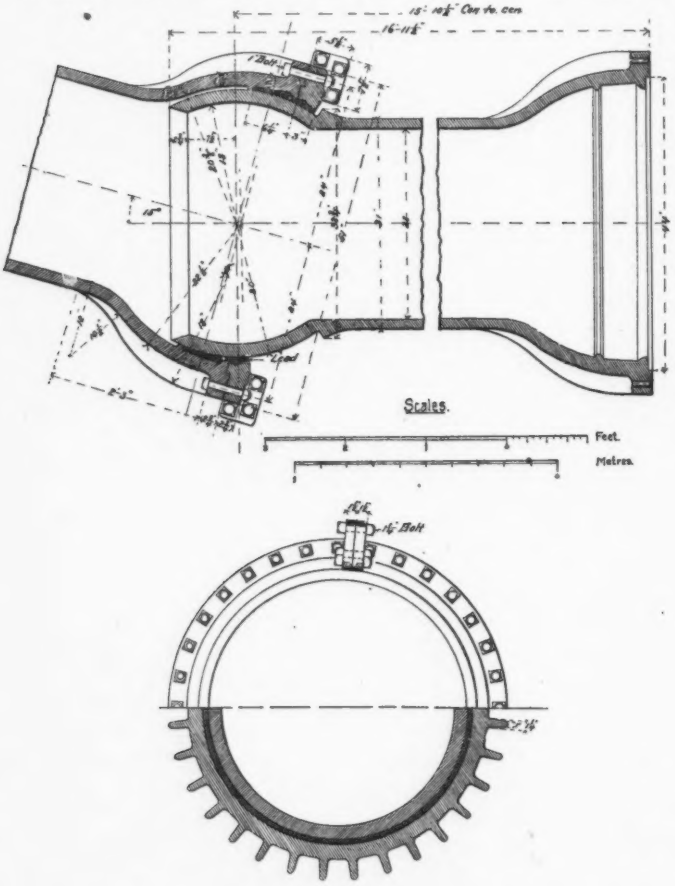


FIG. 1.

proposal a design of a flexible joint. The Oregon Bridge Company (of which the authors are members) was the lowest bidder. This firm's bid was for cast-iron pipes provided with the well-known Ward joint. All

bids were again rejected. About a month later the Oregon Bridge Company was requested by the Chief Engineer of the Water Committee, Isaac W. Smith, M. Am. Soc. C. E., to submit a proposal for cast-iron pipes provided with flexible joints, the design of which had been prepared in his office. This design will be readily recognized as a modification of the Fanning joint (see Fig. 1).

The revised bid of the Oregon Bridge Company was accepted and the contract promptly awarded.

Specifications.—The conditions and requirements of the contract will be best understood from the sections of the specifications appended to this paper (page 269).

Furnishing the Pipes.—Soon after the award of the contract, the contractors requested bids for furnishing the pipes from 16 of the leading pipe foundries in the United States. As the manufacture of these pipes necessitated special preparations and additional appliances, all but three of the foundries declined to bid. Two of these, the Addyston Pipe and Foundry Company, of Cincinnati, and the Ohio Pipe Company, of Columbus, varied but little in the amounts of their bids, and it was exceedingly difficult to decide between them.

The contract was, however, finally awarded to the Ohio Pipe Company, which agreed to manufacture the pipes in lengths of nearly 17 ft., 4 ft. longer than the Addyston Pipe Company would agree to furnish them. The advantages in favor of the long pipes are obvious. One hundred and twenty-six of these pipes would complete the contract, while 166 of the shorter pipes would be required. In the cost of laying there would be a clear saving of 25%, since the cost is largely, if not wholly, governed by the number of joints. In addition to this there would be a saving of about 8 tons of lead, and about 100 tons of freight.

Delivery of the Pipes.—Although it was stipulated in the contract with the manufacturers that the pipe should be delivered at Portland on or before June 1st, owing to delays at the shops and to railroad strikes later on, it was August 20th before the last pipe arrived.

The manufacturers took particular pains in loading the cars to secure the pipes thoroughly, the result being that the entire shipment came across the continent without receiving the slightest injury.

The pipes were unloaded from the cars with a two-way derrick, connected with a stone-cutting yard near the east bank of the river, and

were then rolled down a skidway to the water's edge, whence they could be transferred to the derrick scow as they were needed.

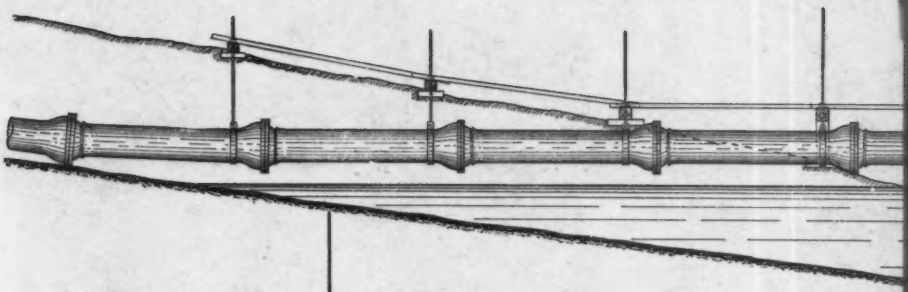
Dredging.—The work of dredging the trench for the pipes began on the east side of the river about August 1st. A stern-wheel steamboat, fitted up with buckets attached to an endless chain operated from one side of the boat, forming a bucket dredge, performed the entire excavation in a perfectly satisfactory manner. As will be seen by referring to the profile (Fig. 3, Plate XXX), the depth of the trench varied from 8 to 23 ft. The width at the bottom was from 10 to 12 ft. With the exception of about 250 ft. on the east side, and about 300 ft. on the west side, the material consisted for the most part of fine gravel and coarse sand. On the east side the bed of the river consisted of boulders and hard pan firmly cemented together. The excavation of this portion of the trench progressed so slowly that nearly a month was consumed before it was completed. On the west side soft mud (deposited from a sewer which discharged into the river immediately above the pipe line) was encountered, making it necessary to dredge to a depth of 23 ft., to secure a solid bed for the pipes. Here, also, slow progress was made, owing to the inflow of mud from the sides of the trench. Even after firm material was reached, the trench became partially filled with mud before the pipes could be laid; but they readily sank through the soft mud to a solid bearing.

Occasionally trees, logs and snags were found buried beneath the bed of the river, which added somewhat to the difficulties of the work, but they were promptly disposed of by the use of powder and a snag-boat whenever they interfered with the dredging. The hull of a vessel completely buried in the sand was torn into fragments by powder before it could be removed.

The dredge was kept on the line by means of a row of piles driven about 35 ft. apart (except in the channel) above the pipe line at a convenient distance from the trench. These piles were afterwards used for keeping the pipe-laying barges on line.

About 18 500 cu. yds. of material were excavated with the dredge—an average of about 10 cu. yds. per linear foot.

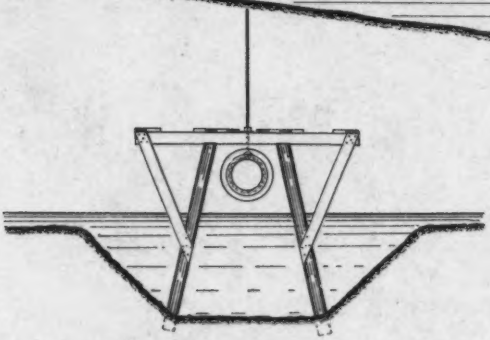
Rejected Pipes.—During the month of August all preliminary arrangements were completed for beginning the work of pipe laying. The cradle (Plate XXXI) which had been framed on the pipe-laying barges, was in position ready for duty; a number of pipes had been delivered



Subm

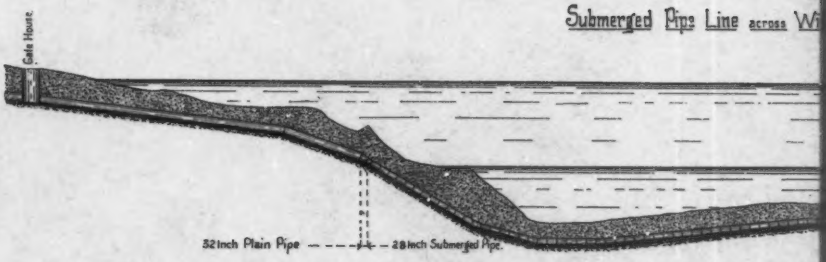
across Willamette Ri

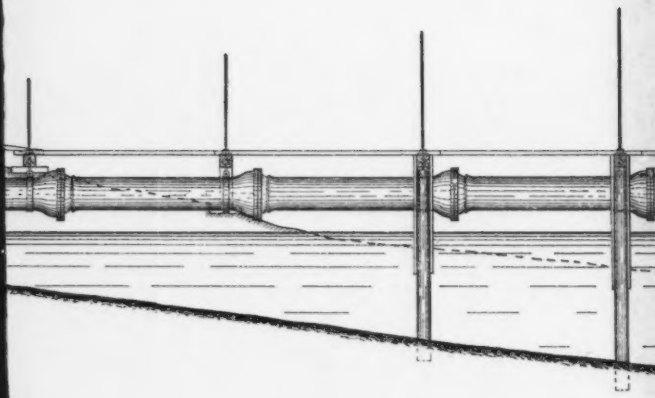
Method of Laying



Front Elevation of Bents.

Submerged Pipe Line across Wi





Submerged Pipe Line
across Willamette River at Portland, Oregon.
Method of Laying in Shoal Water near Shore.

FIG. 2.

Submerged Pipe Line across Willamette River at Portland, Oregon.– Profile of

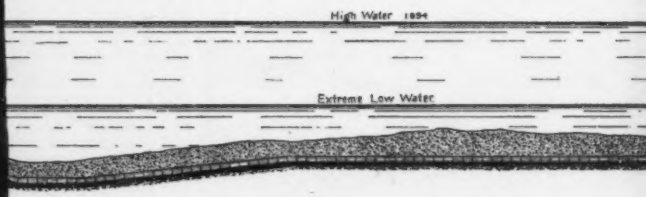


FIG. 3.

PLATE XXX.
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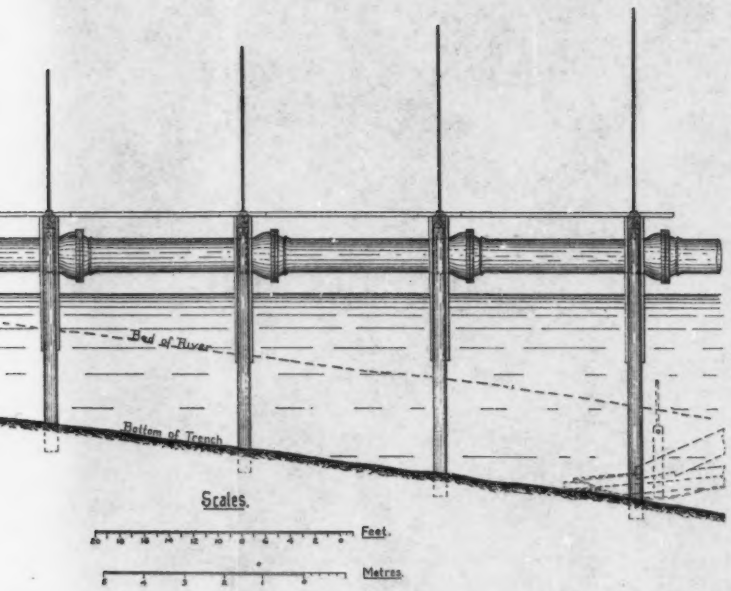
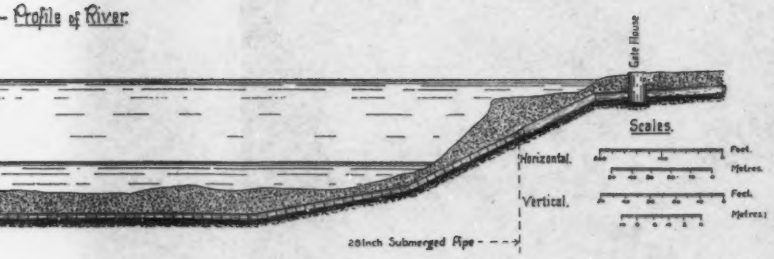
RIFFLE ON SUBMERGED PIPE LINE.



Profile of River.



on board the barges and tested in the testing machine, and the contractors were ready to begin laying pipe on September 1st, when a letter was received from the Chief Engineer stating that the local inspector had reported that the ball ends of the pipes had not been finished to a truly spherical surface, and that he would require the defects to be remedied before he would permit the pipes to be laid. This discovery of alleged defects in the pipes, after they had passed the inspection of the shop inspector, placed the contractors in an embarrassing position. To turn the ball ends of the pipes again would require the construction of a special lathe, during which time the work of pipe-laying would be postponed indefinitely, probably until it would not only be hazardous but foolhardy to begin the work, owing to the sudden and frequent rises in the river during the winter or rainy season. In other words, to remedy the defects as required by the Chief Engineer, meant a delay of one year, and the contractors were under heavy bonds to complete the work by November 1st, 1894, the forfeiture for non-completion of the contract within the time specified being $200 for each day's delay.

Before taking further action in the matter, the Chief Engineer consented to permit the contractors to lay several pipes in the trench on the east bank on condition that the joints be tested to his satisfaction. A connection was made with the 32-in. main at once. As fast as each pipe was laid and the joint calked, the end of the pipe was raised high enough to revolve the ball end 15° in its socket, and was then lowered to a bearing in the trench. After eight pipes had been laid in this manner a cast-iron cap was bolted to the end of the last pipe, and a pressure gauge was attached. Water was then admitted through the gate on the 32-in. pipe line, the water having been supplied by the East Portland Water Works for this experiment. At 10 lbs. pressure every joint leaked considerably. The contractors desired that the pressure be increased, but the Chief Engineer believed that the defects could be best demonstrated to exist by using a light pressure. The experiment, however, was continued with an increase of pressure. It was soon apparent that the leakage diminished as the pressure increased, until at 45 lbs. pressure it ceased entirely, the eight leaky joints having become absolutely tight.

The contractors were now convinced that they could make the joints of the entire submerged pipe line practically tight as the work pro-

gressed, whether the ball ends were defective or not. But after having laid three more pipes a peremptory order from the Chief Engineer was received to suspend operations until action could be taken by the Water Committee. The Water Committee did not meet to consider the matter until a week later. In the meantime the Chief Engineer formally notified the contractors that his chief inspector had carefully examined the 16 pipes lying on the pipe-laying barges, and, acting on his inspector's report, he had rejected 13 of the pipes as not fulfilling the requirements of the specifications.

At the meeting of the Water Committee, the Chief Engineer took the position that the ball ends of the pipes were not truly spherical, and advised that they should not be accepted until they were made to comply with the specifications. The contractors argued that the lathe work had been performed under the personal supervision of a competent inspector appointed by the Chief Engineer; that the pipes having been once inspected and accepted through a duly authorized agent, it was unfair to refuse to accept them because a second inspector found fault with the workmanship nearly three months after they had left the shops, and six weeks after they had reached their destination; that in the absence of specifications for the lathe work the only test to be applied was that of adaptability to the requirements of the contract; that the workmanship on the ball ends was of such a character as to permit them to move in their sockets with the greatest ease while the pipes were being lowered into position, and that whether the joints leaked or not was immaterial so long as they were made tight after the pipes were in the bottom of the trench; and that the test imposed by the Chief Engineer was contrary to the specifications, the final test being the only one prescribed.

The Chief Engineer refused to believe that the joints could be "pulled" tight by hydraulic pressure, except under the most favorable conditions, and argued that such conditions would not prevail in the bottom of a trench excavated in the bed of the Willamette River.

The Water Committee decided to permit the pipes to be laid, and to make the payments as stipulated in the contract, the contractors to be held responsible for all rejected pipes. As, under the terms of the contract, the contractors were held responsible for all the pipes laid, whether perfect or defective, they promptly accepted these terms.

While some of the members of the Committee undoubtedly believed

the undertaking would prove a success, there is no doubt that the Committee was largely influenced by the fact that the re-turning of the ball ends of the pipes would postpone the completion of the new water system another year, during which time the city would be paying interest on bonds to the amount of more than $2 000 000 without receiving the slightest benefit in return for this outlay.

It is to be regretted that the three accepted pipes were not subjected to the same test as the first eight pipes laid, for the authors confidently believe that they also would have leaked under like conditions. While it is altogether probable that radial inequalities of $\frac{1}{100}$ or even $\frac{1}{1000}$ in. in the ball end of a flexible joint may be the cause of more or less leakage, on the other hand it is extremely doubtful if the most accurate lathe work attainable would insure an absolutely tight joint under the conditions of the imposed test. During the experiments it was observed that the leakage was in every case confined almost entirely to the upper portion of the joint, the extreme lower portion being tight. This naturally suggested a secondary cause of leakage, which the most accurate workmanship would not overcome, viz., the extreme weight of the pipe. Each pipe weighs very nearly 5 tons. As the pipes lay in the trench, their weights were so distributed that a comparatively small portion of the entire weight was borne by the sockets. But in lifting the ends of the pipes 4 ft., the test imposed, the additional weights thrown on the sockets had the effect of slightly compressing the lead beneath, which, of course, produced more or less leakage in the upper portion of each joint.

It may be interesting in this connection to know the extent of the defects which caused the rejection of 13 out of 16 pipes. The inspector on the pipe-laying barges was instructed to test the surface of the ball end of each pipe, and to keep a record of the radial variations. Although the methods employed were more or less crude, it is believed that the work was done conscientiously, and that the results are sufficiently accurate for the purpose. The examples given below have been kindly furnished by the inspector. The variations were measured with a micrometer on the line of the axis of the pipe, and are expressed in thousandths of an inch. Column 1 contains the shop numbers marked on the pipes. Columns 2 and 3 contain the amounts of radial variation near the edges of the ball at equal distances from the center. These variations are maximum in each case,

and the 12 numbers selected present a fair average for the entire lot of pipes.

Number of Pipe.	Variations from radius at center, measured near each edge.		Number of Pipe.	Variations from radius at center, measured near each edge.	
25	−0.005	−0.012	84	+0.009	+0.009
35	+0.010	+0.010	95	0.000	−0.012
45	0.000	−0.007	106	−0.013	0.000
55	0.000	−0.012	115	−0.011	0.000
65	0.000	−0.013	125	0.000	0.000
75	+0.012	+0 012	130	0.000	0.000

An inspection of these data shows a lack of uniformity in the nature, as well as in the extent, of the inequalities on the surfaces of the balls. Nos. 35, 75 and 84 were evidently flattened at their centers. This flat zone was found in most cases to be 1½ or 2 ins. in width. This feature was reversed in No. 25, there being a projection on the central zone about 2½ ins. in width. Nos. 125 and 130 were pronounced perfect. The remaining cases cited above were apparently perfect on one-half of their surfaces only.

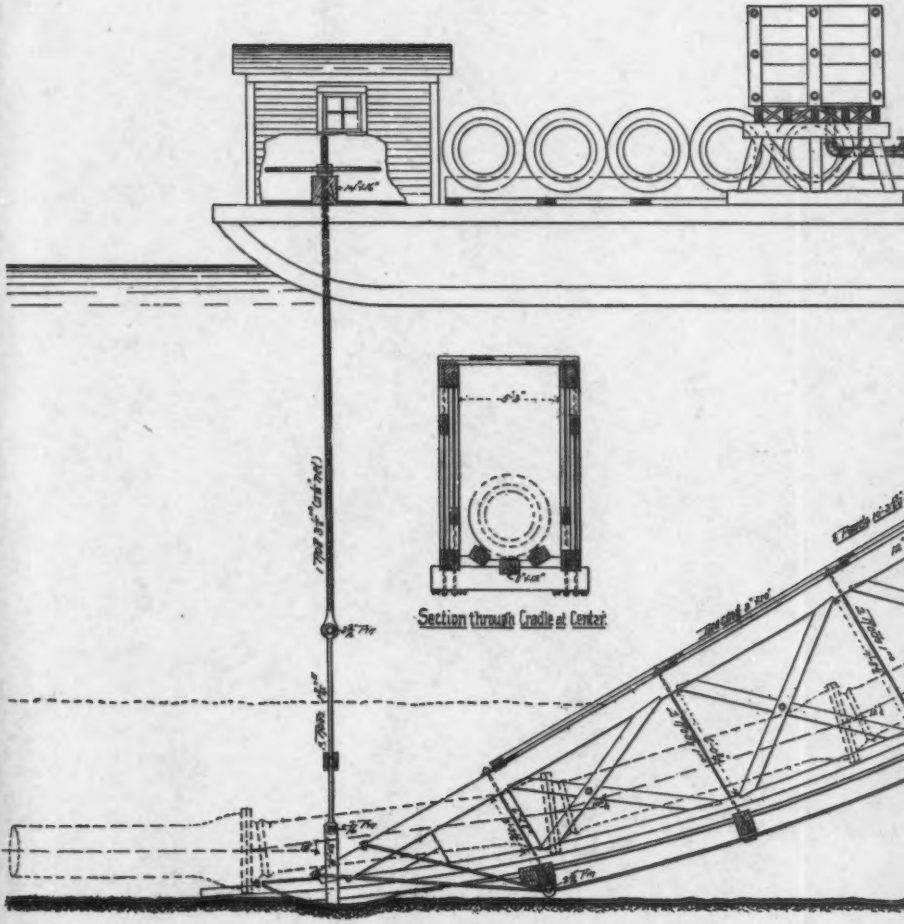
Local machinists and mechanical engineers who were consulted by the Chief Engineer almost with one accord regarded these radial variations as evidences of exceedingly poor workmanship. The chief inspector in his written report to the Chief Engineer expressed the opinion that the inequalities on the surfaces of the balls would render the joints inflexible, that there could be no "articulation," as he expressed it.

It is to be hoped that this phase of the subject will be thoroughly discussed by those members who have had experience with ball and socket-joint pipes.

Description of Pipe-Laying Device.—The apparatus used for depositing the pipes in the trench was designed by the authors. The method of using this device is clearly shown in the accompanying plates.

For laying in shallow water near each bank trestle bents were erected, one for each pipe, from which the pipes were suspended by long screws 1¼ ins. in diameter, by means of which they were gradually lowered into position (see Fig. 2, Plate XXX).

For laying in deep water a cradle (see Plate XXXI), constructed in the form of an inverted bowstring, was employed. One end was supported and pivoted between two barges, placed 10 ft. apart, while



Section through Cradle at Center

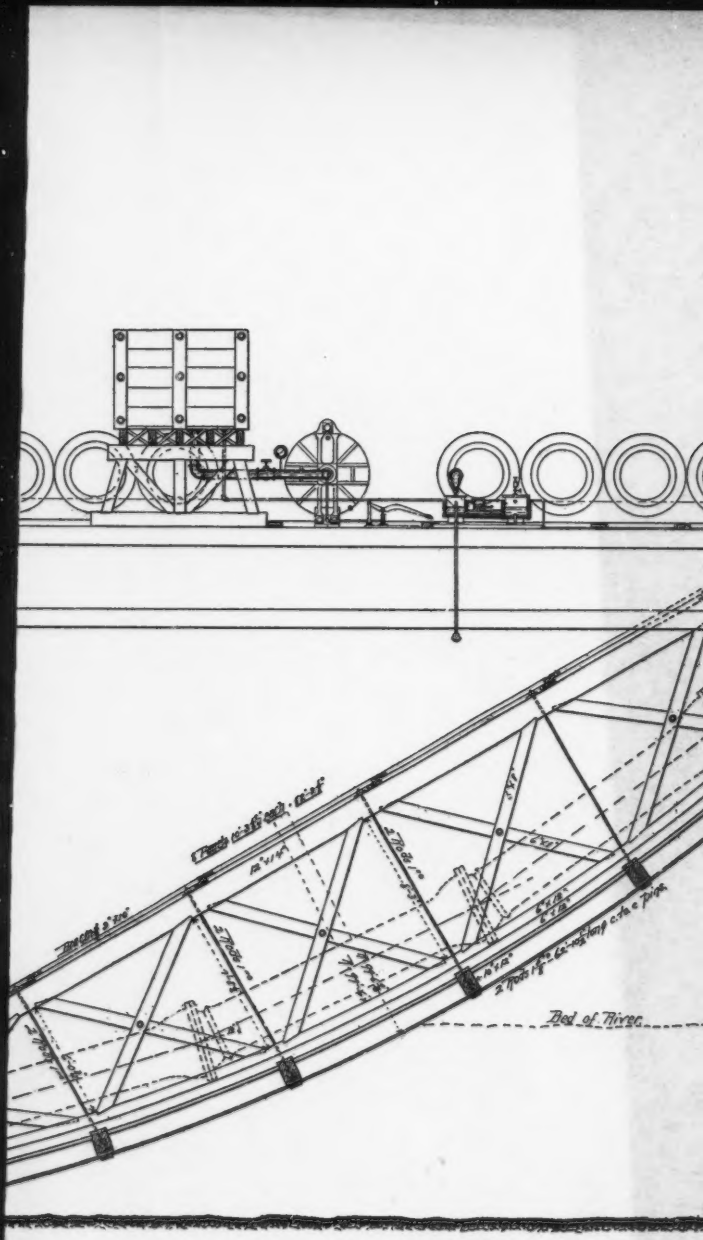

Bed of River

PLATE XXXI.
TRANS. AM. SOC. CIV. ENGRS.
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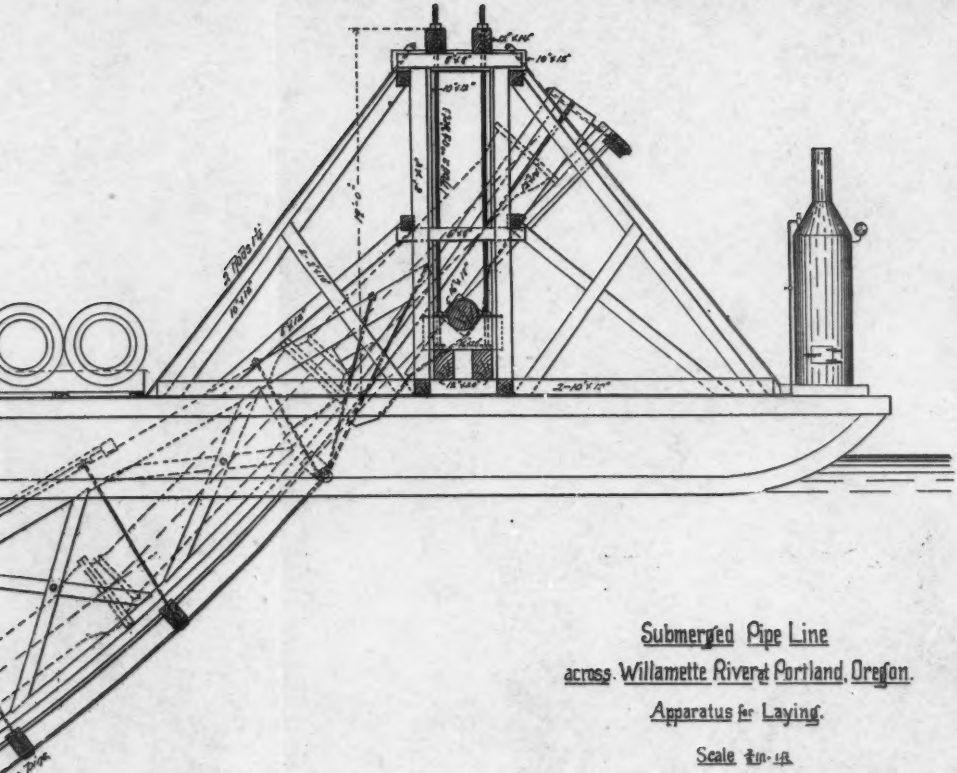
RIFFLE ON SUBMERGED PIPE LINE.



Submerged Pipe Line
across Willamette River at Portland, Oregon.
Apparatus for Laying.

Scale 1/8 in. = 1 ft.

Feet.

Metres.

Datum of Trench

the other end was suspended between the barges at the rear by a long rod, which was always so adjusted as to permit the cradle merely to touch the bottom of the trench.

The stresses in the cradle were carefully calculated, a factor of safety of 10 having been used in determining the dimensions of the various members. This may appear absurdly large at first thought, but after noting the severe treatment the cradle received during its progress across the river, not only from the imposed load, but from such extraneous influences as heavy swells from wind and passing steamboats, the authors are convinced that the factor used was none too large for the requirements.

All wooden members in the cradle consisted of full-length timbers, those forming the bottom chord being 100 ft. long. An auxiliary bottom chord, consisting of two 1¾-in. round rods, was added as a precaution against a possible weakening of the timbers, caused by bending them to the required radius.

The beam supporting the forward end of the cradle rested upon trunnions held in place by four 8 x 12-in. vertical posts, which served as guides. These posts were securely braced in three directions, and were capped by 12 x 14-in. timbers, through which two rods, each 2 ins. in diameter, passed to the trunnions below. This arrangement answered the purpose of a lift for the forward end of the cradle. The height of the frame was sufficient for a maximum elevation of 17 ft. This device made it possible to maintain a uniform angle of inclination for all depths of water.

Two 12 x 20-in. beams were laid side by side under the trunnions, the ends being supported on the centers of the barges. Whatever the position of the trunnions, blocking was inserted between them, while the rods were kept sufficiently slack to throw the weight directly on the beams.

The hanger from which the rear end of the cradle was suspended consisted of a 3¼-in. round rod, with threads cut its entire length, hung from a 14 x 16-in. beam laid crosswise of the barges. The lower end of this rod was connected with a curved stirrup attached to the cradle.

The slide, on which the pipes were connected, and down which they moved into the trench, was composed of three 8 x 12-in. timbers laid flat on 10 x 14-in. floor beams. The timbers were shod with flat

rails, spiked every 2 ft. with countersunk rag spikes. Two lines of rails were laid on the center stringer and one on each outside stringer. The rails were used for the double purpose of reducing friction between contact surfaces, so that the pipes would slide easily, and of preventing excessive wear on the timbers. The slide was made to conform in cross-section to the outer circumference of the pipe joints.

To provide a continuous slide to the bottom of the trench an apron was attached to the cradle, being hinged at the first panel. The apron was shod with heavy plate iron. It answered the purpose admirably, even on the east side where there were many boulders.

Pipe Laying.—Pipe laying began on the east bank September 21st. The first 12 pipes were connected and suspended from the trestle bents previously referred to, just above the water-line. Five pipes were connected and suspended from cross-timbers on the pipe-laying barges directly over the center line of the cradle, which was suspended only a few feet below the water-line. The barges were then moved into position at the end of the trestle, and the two sections were connected. This formed a continuous line of 17 pipes suspended over the water. The pipes were then gradually lowered by means of wrenches until the last five rested on the cradle, when the top lateral bracing was put in place. As soon as this was accomplished, the pipes suspended from the trestle bents were lowered simultaneously with the cradle to the bottom of the trench.

Laying from the cradle then began, and the work was prosecuted vigorously until shoal water was reached on the west bank. The pipes on the cradle were then suspended by long screws from timbers laid across the barges, the cradle was pulled out of the way, bents were erected, and the pipes were suspended and lowered as on the east side.

The weight of the pipes on the cradle tended to push the pipe-laying barges ahead. Four 2-in. stern lines fastened to pipes already laid, and extending to snubbing-posts on the barges were used to prevent any forward movement while the joints were being made. When ready to move ahead, men stationed at the snubbing-posts slowly and steadily slackened the lines, until the cradle moved the required distance. The lines were then made fast, and two more pipes were connected.

At times, owing to an ebbing tide or an abrupt change of grade in

PLATE XXXII.
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RIFFLE ON SUBMERGED PIPE LINE.

the bottom of the trench, the end of the cradle would sink into the sand and gravel sufficiently to arrest the movement of the barges, even though the lines were slack. This difficulty was overcome by a few turns of the wheel wrench which operated the rear suspension rod.

The barges were kept on the line by means of a float or raft made of piles attached to the up-stream barge and fitted between it and the row of piles described under the head of dredging.

While laying pipe with the cradle 16 men were employed as follows: Foreman, 1; engineers, 2; testing the pipes and cleaning the ball ends, 6; melting lead, 1; pouring lead, calking and bolting, 6. Two members of the contracting firm were present most of the time the work was in progress. An expert diver was also employed continuously. With the exception of the diver, Mr. Ivar Johnson, of Chicago, none of the men had ever been employed on similar work. It required some time, therefore, to train them thoroughly before the work progressed smoothly. Two weeks of almost continuous rain also impeded the progress to some extent. Nevertheless, 100 pipes were laid in 20 days, an average of about 80 lin. ft. per day. This required 10 lead pourings and calkings for 40-in. joints, and the bolting of five sleeves, each containing 38 bolts, to the flanged sockets of the pipes. Toward the close of the work, during exceptionally fine weather, from six to eight pipes were laid per day of 10 hours.

The line of pipes was tested by hydraulic pressure about every 200 ft. laid. When ready to test, the cast-iron cap, referred to elsewhere, was bolted to the flange of the last pipe on the cradle. Water was admitted through the gate on the east bank. Pressure was then applied by a double-acting steam pump, located on one of the barges. The pressure was continued until the derrick scow returned with a new load of pipes—usually the greater part of one day. During these tests the diver carefully inspected each joint and the pipes in general as they lay in the bottom of the trench. Leaks were easily located and were promptly calked. But little calking under water was necessary, however, the line being practically tight from first to last.

In making frequent tests the contractors had two objects in view; first, the final tightening or calking of the joints as they lay in position by pulling the ball ends tightly into the lead; second, the detection and stoppage of any serious leaks before the pipes became covered with sediment. That the "pulling" process was a success is fully

proved by the following instance: When about 650 ft. of the pipe line had been laid, a pressure of nearly 250 lbs. per square inch was applied for a few minutes; this had the effect of pulling the joint at the reducer, which connected the 32-in. line with the submerged line, an additional ¼ in. This joint had been started by previous tests, but in this instance the increased pressure gave the joint an extra pull, although the power was applied 650 ft. distant. The weight of the pipes laid when this test was made approximated 200 tons.

During the several tests it was impossible to determine the condition of the line with any degree of accuracy on account of the leaky condition of the gate. It was considered a good indication, however, that at the last test the pressure gauge stood fully as well as at the first test, when every joint was visible and showed no sign of leakage. For this reason it is believed that the ball and socket joints are practically tight.

The line was subjected to 13 tests, including the final test prescribed in the specifications. This test was made after the line was connected with the 32-in. main on the west side, and consisted of a continuous pressure of 200 lbs. per square inch for a period of 24 hours. According to the report of the engineer who conducted the test, the leakage was about ¾ gall. per minute. Although an attempt was made to determine the amount of leakage in the two gate chambers and at the pump connections, no accurate results were obtained. It cannot be assumed, therefore, that the submerged pipe line is responsible for any considerable portion of the reported leakage. The test also included 600 ft. of 32-in. pipe covered to a depth of from 10 to 15 ft.

Broken Pipes.—During the 11th and 12th tests a pipe was broken each time. In each case the break was doubtless caused by the wedging of the ball in its socket, the end pressure concentrating an enormous strain on a comparatively small portion of the socket. The first break occurred in the socket of the second joint from the end, while the second break occurred in the socket of the third joint from the end. In each instance the fracture extended spirally around the pipe for half its length. Four days were consumed in replacing each of the broken pipes. In the first case, it was necessary to drive piles, and to raise several pipes already laid by means of long screws, in order to get the broken pipe above the surface of the water. The first pipe

PLATE XXXIII.
TRANS. AM. SOC. CIV. ENGRS.
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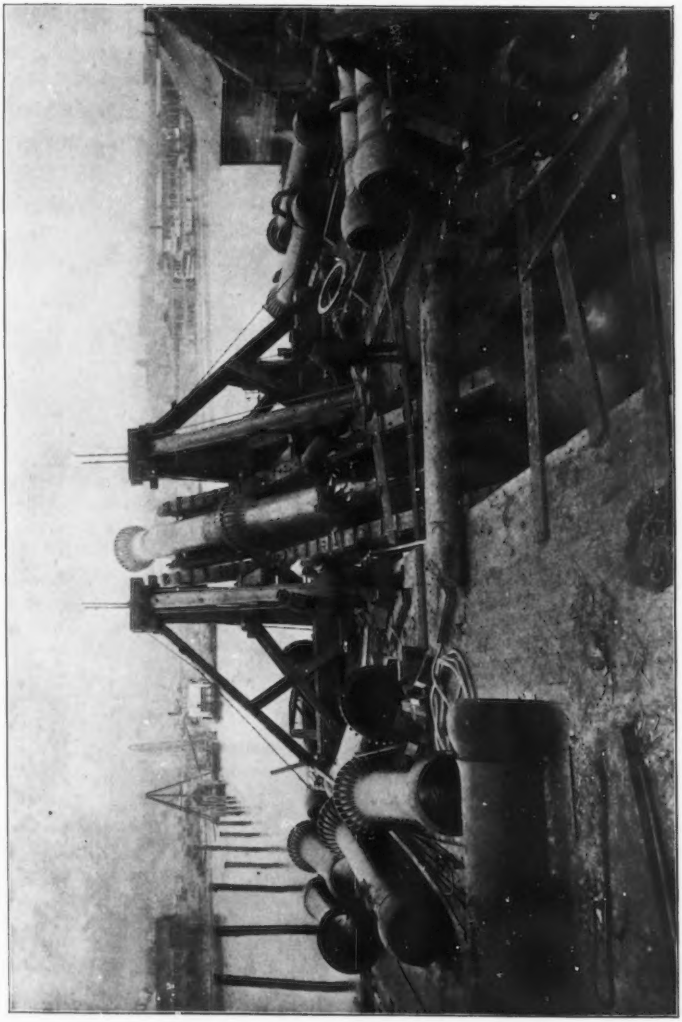
RIFFLE ON SUBMERGED PIPE LINE.



broken showed no indication of a flaw at the fracture; the fracture in the second pipe, however, betrayed very porous metal mixed with cinders. These were the only accidents connected with the work, and they could have been avoided easily by subjecting the pipes to a reasonable end pressure; 150 lbs. per square inch or less would have answered every purpose.

In concluding this paper the authors desire to urge all the members who have had experience in laying submerged pipes to participate in the discussion, and thereby contribute the results of their experience to the profession.

EXTRACTS FROM SPECIFICATIONS.

"4. The pipes are to be laid across and under the Willamette River, above the Madison Street bridge, on the line of either Clay or Mill Street, as may hereafter be determined by the Water Committee.

"5. On either line the width of the river is approximately 2 085 ft. at high water, 1 705 ft. at low water, and 1 270 ft. between the harbor lines established by the United States engineers.

"6. High water is produced by floods in winter, and by back water from the rise of the Columbia River during the summer months of June, July and August, and the pipes must be laid during the months of September and October, when the water is low and there is no current in the Willamette River.

"8. An inspector will be appointed by the Water Committee, who shall inspect and test all the materials required for the pipes, and who shall, for this purpose, have free access to the mills or shops in which the work may be performed under these specifications, and the contractor shall furnish, without charge, to the said inspector, specimens and test pieces, in such number and of such forms as he may deem necessary to determine the character of the material, together with the use of the testing machines, and such assistance as may be necessary in handling and operating the same.

"9. The pipes and joints to be in one casting, as shown in the attached drawing.

"10. The metals of the castings must be poured from remelted pigs of good gray iron, without any admixture of cinder, and the castings must be tough, free from cold shuts or blow-holes, of workmanlike finish, and of such density and texture that they may be easily cut, drilled or chipped.

"12. The ultimate tensile strength, by a direct pull, must not be less than 18 000 lbs. to the square inch.

"13. Test bars 26 ins. long, 2 ins. wide, and 1 in. thick, when loaded in the center, narrow sides vertical, and 24 ins. between supports, shall carry a breaking load of not less than 1 900 lbs., and show a deflection of not less than ¼ in. before breaking.

"23. The pipes to be cast in dry sand moulds, placed vertically, and not to be stripped or taken from the pit while showing color of heat.

"The shells to be smooth and sound, without cold shuts, lumps, swells, scales, blisters, sand holes, or other imperfections; truly cylindrical, of full diameters, and with interior and exterior surface concentric.

"25. The pipes when completed, to be thoroughly cleaned inside and outside without the use of acid or other liquid, and then heated to a temperature of 300° Fahr., and immersed in a bath of equal temperature of coal pitch varnish, or other coating material, to be approved by the engineer of the Water Committee.

"26. Each pipe must then be subjected to a test by hydraulic pressure of 250 lbs. to the square inch, and shall, when under that pressure, be subjected to an additional test by a series of blows at various points throughout its entire length, with a 3-lb. hammer attached to a handle 16 ins. long.

"Should any leak or failure in the pipe be shown during this test, it will be rejected.

"35. A trench is to be dredged across the river, not less than 8 ft. below the bottom, or 23 ft. below the level of low water on the portion of the line between the harbor lines.

"38. As the material dredged cannot be replaced in the river, it must be carried away on scows and dumped where it will not interfere with the navigation of the river, or placed within the harbor lines by consent of the owners of the lands.

"39. Payment for dredging will include the removal of all snags, logs, stones and roots which may interfere with the even bearing of the pipes in the trench, and also the removal of any piles which may have been driven near the east or west shores of the river.

"42. Pipe laying will include the work necessary to connect the ball and socket joints, including furnishing and pouring the lead and the furnishing and handling the dredges, barges, scows, and appliances for depositing the pipes in the pipe trench.

"44. After the pipes have been delivered on the pipe-laying barge, each section will be carefully inspected inside and outside, and will then be subjected, in the presence of the inspector of the Water Committee, to a pressure of 200 lbs. to the square inch, and any pipes that shows splits, flaws, leaks, or other defects, will be rejected.

"46. After the pipes have been laid and connected, they will again be subjected to a pressure of 200 lbs. to the square inch for a period of

24 hours, and will then be connected for a period of 90 days with the distribution system of the city water-works.

"47. All defects and leaks in the pipes developed during the test of 200 lbs. pressure, or the connection with the city mains, must be repaired to the satisfaction of the engineer of the Water Committee, or the pipes replaced at the expense of the contractor in case that the repairs cannot be so made.

"48. The work will not be considered as completed or accepted until after it shall have remained in good working order, without leaks or breaks, under pressure from the city mains for a period of 90 days."

DISCUSSION.

E. KUICHLING, M. Am. Soc. C. E.—While the speaker had no experience with pipes of this kind under great internal pressures, yet he was familiar with a number of lines of flexible jointed pipe which were subjected to slight external pressures, such as intake pipes laid out from the shore into the deep water of rivers and lakes. A riveted steel pipe of this sort, 5 ft. in diameter and about 1 500 ft. long, was laid last fall under his direction in Hemlock Lake, Livingston County, N. Y., as the intake for supplying the new gravity conduit of the Rochester Water-Works. The pipes were riveted together in lengths of about 100 ft., and provided at the ends with the component parts of ball and socket joints shown in Fig. 2 (page 273). These flexible joints admit of a deflection of 17½° in any direction, and are made mostly of steel plates stiffened with bar, angle and channel rings, cast-iron being used only for the spherical zones or ball portions. The latter were riveted with countersunk rivets to short sections of steel pipe, and then placed in a lathe, where the spherical surface was accurately formed with proper tools. The bearings for this spherical surface are formed of lead, which was melted and poured into the channel rings of the socket and collar after the parts had been assembled in the shop. This style of joint was originally designed several years ago by Mr. William H. Law, of Peterborough, Ont., for use in the 4-ft. and 5-ft. intake pipes of the Toronto Water-Works, and was also adopted for the 4½-ft. intake pipe of the Syracuse, N. Y., Water-Works. Mr. Kuichling.

In its original form, however, the chord subtended by the two lead bearings seemed too short, and in designing the joints used at Hemlock Lake, the chord was lengthened considerably by using angle rings of unequal sides. The joint was also greatly strengthened by the introduction of the heavy steel reinforcement rings above or around the bearings. It should be remarked that all of the steel angle, channel and bar rings were carefully welded, and then riveted together, as

Mr. Kuichling. shown in the drawing. The 5-ft. flexible joints referred to weighed about 6 200 lbs. complete each, the weight of the cast-iron zone or ball portion being about 2 700 lbs. They were made by the Central Bridge and Engineering Company of Peterborough, Ont., at the rate of $290 per joint, including all transportation and attachment to the pipe at Hemlock Lake, but exclusive of the United States Customs duty. The steel plate of the pipe is $\frac{3}{8}$ in. thick where heavy back filling of the dredged trench or channel was contemplated, and $\frac{5}{16}$ in. thick where the back filling was light or where the pipe lies directly upon the bottom of the lake. After the joints had been riveted to the pipes, their weight ranged from 14.5 to 18 tons each, according to the thickness of the plate and the number of stiffening angle rings applied to the pipes where heavy back filling occurred. The pipes were laid in water varying from 20 to 35 ft. in depth, each joint being securely bolted together above the surface of the lake, and then lowered into place on the bottom by means of suitable apparatus. All of the joints appeared to move freely and satisfactorily in every respect, and to be quite water tight. As before stated, the pipe was designed for intake purposes only, and will probably never be subjected to a greater external pressure than that due to about 1 ft. head of water. Slight leakage was therefore a matter of no particular account. There is, however, no reason for believing that the flexible joints here used would not be thoroughly serviceable if subjected to internal water pressure.

In designing such flexible joints, it is essential to proportion the parts so that the bell or socket will not burst under the severe internal pressure developed by the action of a force in the direction of the axis of the pipe. For this purpose the reinforcement of a cast-iron bell or socket with a heavy ring of wrought iron or steel is generally expedient, and has frequently been employed in the past. The use of a long subtended chord and a high versed sine is also very desirable. In the case of the Willamette River pipe, it is stated that a water pressure of 250 lbs. per square inch was applied to a portion of the line, one end of the pipe being temporarily capped. A longitudinal force of about 154 000 lbs., or 77 tons, was thus developed, which tended to pull the joints apart; and if the radial component of this force at the junction of the socket with the collar be computed, on the assumption that the same is distributed over a width of 3 ins. along the inner circumference of the socket and collar, it will be found that the lead was then subjected to a pressure of about 1 100 lbs. per square inch. For this particular case the half chord is 3.75 ins., and the versed sine 0.355 in.; but if the collar is also considered, the half chord becomes 6.75 ins., and the versed sine 1.173 ins. These favorable dimensions and the heavy flange of the socket doubtless prevented the loss of more pipes during this severe test.

The pipe was laid in September, when the water was comparatively

Mr. Kuichling.

FIG. 2.

Mr. Kuichling. warm, and the joints were pulled to a tight seat by the great longitudinal force above named. Assuming that a fall of 25° Fahr. in the temperature of the water will occur in the following winter, a contraction or reduction of length amounting to 1 in 6 500 in the cast-iron pipe will occur, which will produce another powerful longitudinal force. If the lead in the joints be regarded as unyielding, this force will be about twice as great as the one caused by the aforesaid test pressure, which produced a stress of about 1 100 lbs. per square inch in the lead packing; hence the contraction will cause a stress of about 2 200 lbs. per square inch on the packing, whereby the metal will probably yield or flow. The socket flange should therefore be proportioned to resist a pressure of from 1 800 to 2 000 lbs. per square inch, which seems to be the point at which lead begins to flow; and it is evident that this has been done in the case of the Willamette River pipe.

The remarkable tightness of the joints in this pipe is very gratifying, and it is to be hoped that other experiments will be recorded which will bring out more fully the merits and reliability of such constructions. It may be urged that while a pipe line of this kind may be tight when first laid, the effect of changes of temperature will eventually give rise to leakage at the joints, and it would be interesting to learn whether such leakage varies with the seasons, being more in summer and less in winter.

The speaker called attention to an interesting account of the manufacture of the pipe and flexible joints at the foundry, given in *Iron Age* of January 10th and 17th, 1895.

Mr. McCann. THOMAS H. MCCANN, M. Am. Soc. C. E.—About 14 years ago, during the laying of a 20-in. force main of which he had charge, it was necessary to submerge the pipe across two tidal rivers, each being about 400 ft. wide, with firm mud bottom and slopes of about 12 in 100, the range of tide being about 5 ft. There was no dredging done. "Ward" joints were used, the calking being done on one shore and the pipe then hauled across the river as each joint was completed, a 40-H. P. engine and heavy chains being used for the purpose. As each joint entered the water, two ordinary standard oil barrels were lashed firmly to the pipe which served to buoy it. When the end of the main had reached far enough up the opposite shore to allow for the extension due to settlement, the barrels were gradually cut loose, and the pipe settled slowly to the bottom. After the water was turned on, a diver was sent down to examine the joints, but he found no leaks. The pressure was about 90 lbs. to the square inch. The maximum depth at high tide in both rivers was 21 ft.

The main has been in constant use during the last 14 years, and an examination made by a diver each summer shows that no leaks have occurred. The pipes are now about half their diameter in the

mud. At one of the banks where the main enters the water down a steep slope of about 30°, one joint on the edge of the shore has pulled out about 2 ins. The time occupied in submerging the main at each river was about a week. Mr. Miles Tierney was the contractor. Mr. McCann.

L. L. TRIBUS, Assoc. M. Am. Soc. C. E.—It is a source of regret that the authors have not given the cost in a little greater detail. It would be of interest to know the exact cost of the 28-in. line. Such work is usually done under contract, and while the total cost may be known, just what the profit or loss was to the contractor cannot be ascertained. Mr. Tribus.

The speaker had recently laid a line of 12-in. pipe on the ice in Morris Lake, New Jersey, and knew the contract price, and about what the actual cost was as well. The ice was some 10 to 14 ins. in thickness. A Ward spherical joint was used every 48 ft., there being two lengths of pipe with ordinary bell joints, then a pipe with a Ward spigot, then one with a Ward hub, each length being 12 ft. long. These were laid on the ice, blocks being put underneath and ropes fastened to a tackle on both sides of the pipe. It was then lowered in water from 6 to 12 ft. in depth, about 50 ft. at a time. After it was laid, it could be seen gradually settling in the mud, owing to the clearness of the water. It seemed to go down very successfully, but tests, to be applied later, can only determine the leakage. This line was about 1 400 ft. long, the pipes averaging about 1 000 lbs. per length. The other line was about 700 ft. in length, laid in water from 10 to 24 ft. in depth, going down equally well, apparently with very little leakage. The question of leakage is comparatively unimportant, as the pressure is very slight and the supply very abundant. The two lines will eventually be connected through a masonry dam, and form the upper or intake portion of the delivery main for supplying Newton, N. J., some 8 miles away.

J. J. R. CROES, M. Am. Soc. C. E.—The expression of cost in terms of amount of material and amount of labor is a great deal more satisfactory than in dollars and cents. If the amount of labor and of material is known, an estimate can be made under local conditions, whereas amounts given in dollars and cents are no criterion for the actual cost in another locality. Mr. Croes.

He was inclined to agree with the authors in the matter of delays and disputes arising from conflicts of inspection. It appeared that the inspector at the shops, several hundred miles away, passed certain pipes which were accepted by the company, and after transportation across the continent were found to be, according to the local inspector, somewhat out of true, and it was only by taking the risk and accepting the responsibility that the contractors were able to finish the work in any reasonable time. He thought that the contractor in this case took a very proper ground.

Mr. Emery. CHARLES E. EMERY, M. Am. Soc. C. E.—His experience was confined to laying pipe with ball joints in trenches on land instead of under water, but he had been much interested in the work of Mr. Ward and others, who had succeeded in constructing water pipe which was flexible while being laid and would remain tight under practical conditions. Referring to the defects mentioned in the paper, he considered from his own experience that it is as easy to turn a ball as to face a plane surface. The tool has but to be guided in a circle and properly set, and the surface operated upon will be spherical. Details are important; for instance, it is necessary that the point of the tool be at the level of the lathe centers, and, in case the tool be carried by a revolving tool-rest on the lathe bed, that the center of this rest be in the center of the shears, or in the vertical plane of the lathe centers; also, that by this method the point of the tool must be at the right radial distance from the center of the tool-rest. When laying the steam pipes of the New York Steam Company he had placed a globular joint every 40 to 50 ft. to remove all strains due to changes in line or grade, and there never was a particle of trouble with any of them. The joints were made in that case with very thin copper, covered with a thin coat of paint, and on breaking such a joint contact was shown all over the abutting globular surfaces. There should be no more difficulty, with proper tools, in obtaining spherical surfaces as accurate as ordinary plane surfaces, as it only requires intelligent inspection, based on knowledge of the way work is practically done in a shop. The inspector must not only be familiar with the result to be attained, but, as a safeguard, he should for unusual details examine the construction and method of operation of the tools, when, with reasonable care, the work will be right. The apparatus used for turning the globular joints of the Steam Company consisted simply of a link of the proper radius hinged at one end to an ordinary traversing tool-rest and at the other to a stationary frame, the traversing screw having been removed. With this construction the tool-rest had only to be fed longitudinally by the motion of the carriage along the lathe shears when the transverse motion required to give circular movement to the tool and form a globular surface was furnished by the swinging of the link.

Billiard and other balls are turned by means of a revolving cutting tool on an arbor transverse to the axis of the lathe, the stock operated upon being meanwhile revolved in the ordinary way.

Mr. Crowell. FOSTER CROWELL, M. Am. Soc. C. E.—In 1868 or 1869 a submarine main was laid across the Schuylkill River with flexible joints that must have been one of the very first instances of the use of the Ward joint. No cradle was employed in laying the pipe. It was lowered from scows, there being several unsupported joints at the tail end of the laying part. The pipe supplied a high-service storage reservoir

and the pressure was very considerable. The pipe was the sole dependence of the reservoir, and he believed that the joints proved entirely satisfactory. Mr. Crowell.

In the Ward joint practical water-tightness seems to be secured without the additional refinement and cost of manufacture advocated by some eminent engineers, to secure perfectly fitting spherical surfaces.

E. Sherman Gould, M. Am. Soc. C. E.—He had no experience in this kind of work, although he had laid a great deal of pipe. He quite agreed with Dr. Emery in saying that a little additional trouble in the shop would save a great deal of trouble afterwards. If the lathes are properly adjusted it is just as easy to turn the pipe perfectly true as not to do so, and he could see no reason why a little extra trouble should not be taken at the start and avoid all the difficulty which seems to have occurred in this case. Mr. Gould.

Frank W. Skinner, M. Am. Soc. C. E.—A simple contrivance for turning flexible pipe joints was installed for the manufacture of the riveted steel submerged intake pipe of the Syracuse Water-Works. This pipe was built by the Groton Bridge Company, which provided some special plant for the construction of the 54-in. straight pipe of which there was about 6 500 ft. laid in water from 15 to 40 ft. deep in rigid sections about 116 ft. long. These were connected by universal joints that permitted a deflection of several degrees in any direction, and were lowered, one at a time, by derricks on large anchored barges. The joints were made as shown in Fig. 3 by a cast-iron spherical segment *G*, riveted to a section *A* of the 54-in. pipe. This end was received in a conical steel piece *B*, bolted at the other or small end to a regular section of the 54-in. pipe, and making a tight sliding contact on the casting *G* by a lead packing *D*, beld in a stiff riveted annular socket *C*. Mr. Skinner.

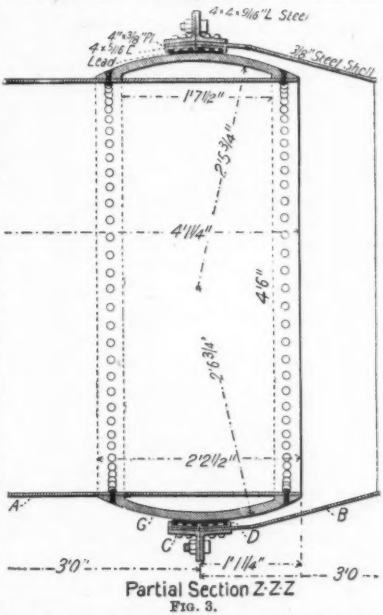


Fig. 3.

Mr. Skinner. In order to turn the spherical surface of casting G, a simple machine was designed and constructed by the shop superintendent at a

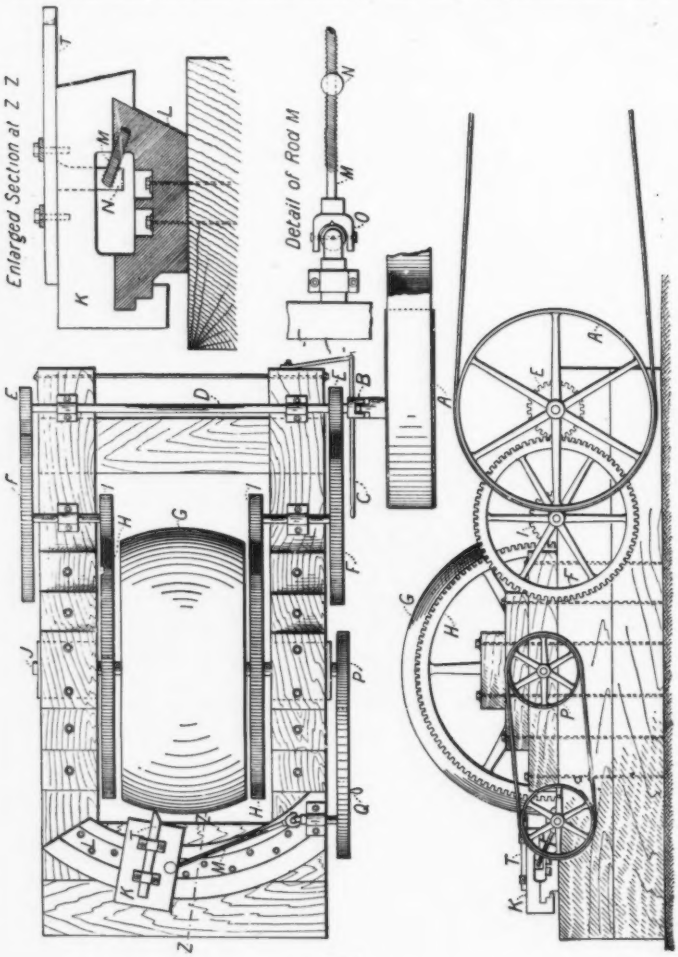


FIG. 4.

cost probably not exceeding $50. Fig. 4 shows the general arrangement and operation without exact scale or dimensions.* The machine

* See the *Engineering Record*, Feb. 9th, 1895.

was made with old gear wheels, etc., which happened to be in stock. It was solidly set in a heavy timber frame and was operated by the lever *C* commanding the clutch *B* which engaged the loose-running driving wheel *A*. The spherical segment *G* was secured to the shaft *J*, which was turned by double sets of gears *H*, *I*, *F*, *E*, driven by the shaft *D*. Mr. Skinner.

The tool *T* was set in the carriage *K* which traveled on the circular arc of the track *L*, concentric with the sphere. The tool was automatically fed by the screw-rod *M* turning in a nut *N* in the carriage *K*. A belt from the pulley *P* of the shaft *J* to the pulley *Q* actuated the rod *M* through the knuckle joint *O*, and a handle was provided for backing it up quickly.

CORRESPONDENCE.

JOHN F. WARD, M. Am. Soc. C. E.—The first trouble mentioned in the paper was, "that the ball ends of the pipes had not been finished to a truly spherical surface." The method of inspection by micrometer measurements as used in finding the amount of imperfection in form, is called by the authors "crude," but, perhaps, "badly chosen" would convey the idea better. Attention is called to a far simpler method of detecting the inaccuracy of the zone of a sphere, which is to use a plain ring of suitable size (which in this case would be about 18 ins. in diameter), bored and faced truly in a lathe. This, if simply laid on the alleged spherical part of the pipe, will show by its contact whether there are any high places, and a flat space of 1½ or 2 ins. in width would show in a rather startling manner, without the work of calculating the ordinates of the curve. Mr. Ward.

The experience gained in this work shows clearly that the bad turning of the ends of the pipes did not in any degree prevent a very good result, and the securing of a reliable and, in every way, first-class job. The apparatus used for depositing the pipes in the trench and the method of operating it was not new; it was clearly shown in *Engineering*, Vol. XI, page 398, London, 1871.

He thought the starting of 650 ft. of the line of pipe, weighing 200 tons, by a water pressure of 250 lbs. per square inch in the pipe, an interesting piece of experience, as it shows a static friction on a sand and gravel bottom of considerably less than 50% if the joint at the large end of the reducer was the one which was started by the pull, or less than 38% if the small end was the one that moved.

If both joints were equally well made, the larger one being the stronger only in the proportion of, say, 100 to 87, and the relative proportionate pull being as 100 to 76, the larger joint should have moved.

Mr. Duane. JAMES DUANE, M. Am. Soc. C. E.—He had laid a number of lines of submarine water pipe, under various conditions, and is now making a design for a 36-in. flexible-jointed main. The paper is of great interest, especially the sketch and description of the cradle used, but he believed that the form of joint employed by the authors is in every way inferior to either the regular Ward joint or to that designed by himself and adopted as standard by the Croton Water Department, New York.

The fact that two of their joints failed under the pull due to the pressure used in testing shows structural weakness that would have been fatal to the success of a line laid under the extremely unfavorable conditions that are sometimes encountered here.

It is questionable if the convex ball spigot can be as readily or accurately turned truly spherical as can the concave hub, still the excessive accuracy demanded by the Chief Engineer of the Portland Water-Works seemed to be unnecessary, and unattainable at any reasonable cost. The writer never demanded nor expected such close work, and never had any trouble as to perfect flexibility; and granting that slight imperfections in the spherical-turned surface may cause leakage when the joint is rotated, it must be remembered that the tightness of joints of this form is dependent on their being laid on their final bed under a strong tensile strain. This practically calks the entire lead joint at one operation, and, as the lead is sufficiently ductile to fill all reasonable irregularities, and sufficiently inelastic to remain where put, the slight departure from theoretical form cited is of no practical importance.

He also differed from the authors' statement that "the advantages in favor of the long pipes are obvious." His experience had been that the greater the flexibility, viz., the shorter the pipes, the less the strain on each joint in laying, and the better the line accommodates itself to irregularities in the bed. In the first line laid 12-ft. lengths were employed which he had since reduced to 9 ft. as a standard, while in some cases, where extra flexibility was required, 6-ft. lengths were used to good advantage. For splicing breaks, lengths as short as 4 ft. have given excellent results on account of ease of handling and shortness of curve.

Although the first cost of short pipes is greater, they are preferable because of the greater certainty in laying and the avoidance of necessarily expensive repairs, especially those involving the employment of a diver, and amply repay for the small additional cost; while, in case repairs do become necessary at any time, the more flexible the line, the more expeditiously and cheaply can they be made.

A main he had laid to Ward's Island embodied all the good points and remedied the defects brought out in an extensive experience. The special features of this design are the wrought-iron reinforce

band shrunk over the hub, and the rounding off of the sharp cutting edge at *B* (see Fig. 5). This band, when properly proportioned and shrunk on, absolutely insured the hub from bursting against any tensile or cross-strain to which it could reasonably be subjected. Mr. Duane.

In repairing a line on which a large vessel had sunk, it was necessary to break the pipe in several places in order to obtain free ends to splice. To accomplish this, the powerful derrick of a wrecking boat was used, and the joints parted either by the spigot shearing through the lead joint, or, in case of sharp bending, by the crumbling away of the inner edge of the hub at *B* to a sufficient extent to allow the spigot with its lead ball to escape. In no case was a hub split, which is the usual method of failure with the ordinary cast-iron pipes.

In the first pipe line laid, the sharp cutting edge was left just as it came from the planer. It was soon found, however, that when the

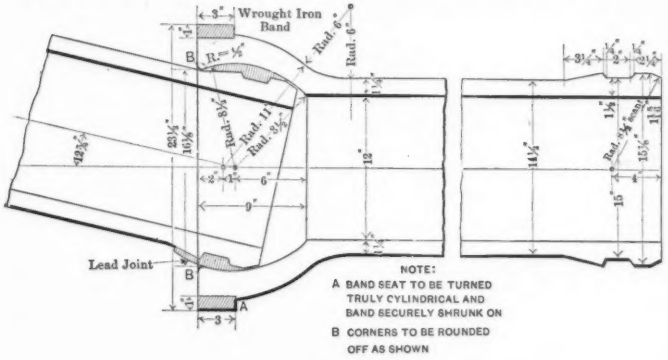


FIG. 5.

joint was rotated, this sharp edge itself acted as a plane and took off a shaving of lead at each motion, with the result that it was extremely difficult to pull the joints tight afterward. The rounding above mentioned obviated this difficulty satisfactorily.

The following brief description of the worst break he has yet had to repair illustrates the facility with which this form of pipe may be handled even under unfavorable conditions.

A 12-in. line laid across the East River (Hell Gate) to Blackwell's Island parted in about 70 ft. of water, where the great depth of water, the irregular, rocky bottom and the great velocity of the current (6 to 8 ft. per second being common), all combined to make the work one of special difficulty. The intervals of slack water were so short that a diver could work only about 30 minutes to a tide, and it took him two days to locate the break. It was found that one of the wrought-

Mr. Duane. iron bands had parted, owing to a defective weld, and that the unsupported hub had then split, permitting the line to pull apart. This is the only accident due to this cause that he ever had. The broken ends were brought to the surface about noon, and before night the splice had been made, by inserting six 4-ft. lengths, the pipe lowered into place, and the water turned on.

In lowering the pipe a strain was kept constantly on the right of the pipe line and the scow allowed to sag down stream, thus pulling all the joints taut in the shape of a horizontal bow. This occurred four years ago, and the pipe has worked all right ever since.

The cost of these lines laid has varied from $7 to $11 per linear foot, dependent upon the price of iron and the natural difficulties to be overcome, amount of dredging, excavation, etc. This price includes all labor and materials complete, with a one-year guarantee. This form of joint had been thoroughly tested, and he could recommend it as being economical in first cost, and as thoroughly efficient. It is not patented.

In closing, he wished to ask the author the following questions: How were the joints run? Was the rib cast on the inside of the hub an efficient stop against the lead running through, or was a yarn gasket, clay dam or other similar device employed? Were the joints run and calked in two separate operations, as described by Fanning? His experience had been that the lead should be run at one pouring to make a homogeneous joint, and that this is more essential than is calking to insure against leakage. If the pipe is laid under a suitable tension, calking may be omitted entirely without ill effects.

Mr. Dunham. H. F. Dunham, M. Am. Soc. C. E.—The paper, although a valuable one, is unlike many others in being too brief. A paragraph or two in relation to the main channel, the amount of shipping for which provision had to be made and the controlling factors in the design of the work would have been acceptable, as also a few general facts in regard to cost, such as the difference in price per ton between common pipes and the pipes purchased, the cost of lathe work, cost of cradle, etc. While the work was undoubtedly carried out to the satisfaction of the parties interested, still questions naturally arise which may be without the province of the authors to answer; as, why, for instance, were the elaborate cradle and its appurtenances constructed? Why was each joint a flexible one? Or, why were any flexible joints at all introduced? And, why was the integrity of an important line left dependent upon the threads of 1-in. iron bolts and nuts which may be exposed in the river bottom to corrosive substances? It does not appear from the description of the material in the bottom of the river that any movement of the pipe due to shifting channels or any other cause is to be anticipated. The description and the sketches alike fail to show any reason why a submerged line could not have

been laid with common pipes and bell joints, each one of which would be as good as joints made on dry land and a few of them rather better than such ordinary joints. For nearly 10 years, work of this kind has been successfully and cheaply carried out by contractors in this country for river crossings, lake intakes, etc. Nothing more plainly shows the difference in the two methods and the great advantage of the modern way than the attention given to tests as the work went on. Had the line been laid in sections with rigid joints the test would have been scarcely more worthy of remark than would the test of the same length of that size of pipe laid in dry ground. The work described appears to have been important enough to warrant exact information in regard to its condition. If a leaky gate prevented this it would have been worth while to repair or replace it. Too much stress seems to have been placed upon exact measurements of parts, and too little upon the relation those parts were to sustain to the whole work. Mr. Dunham.

It would be of interest to know whether gravity or the barge assisted when the joint at the reducer was drawn out ¼ in., and how the proper endwise strain or pull upon the submerged line was continued when the connection was made with the larger pipe at the completed end. An end pressure test for each pipe is referred to as having been omitted, and although the conditions for testing are not fully described, it would appear that each length, or at least the greater portion of it, must have been subjected to an endwise stress of 400 or 500 lbs. to the square inch while in the testing machine. The greater area of the bell end insures this.

The flexibility of a line of cast-iron pipe as ordinarily laid is greater than many suppose. A 10-in. pipe of the writer's design across a river 1 000 ft. wide with abrupt banks, was put together with bends and common joints so as to conform to the dredged channel, then tested and lowered into place by means of screw rods operated by a dozen men. The first man gave his hand wheel three turns and then went to the next, two lengths beyond, which he also turned three times, and at the same time the man who followed him gave the first wheel three more turns, then three men, four men, etc., followed until all were at work and carried an undulatory motion or wave in the line pipe back and forth across the river until it was lowered about 10 ft. While still suspended, fine rip-rap was filled into the trench, to insure a good bearing. No diver was employed. This pipe line seemed perfectly tight, as it held up the gauge pressure. This was six years ago, and no trouble has yet occurred. The pressure varies from 60 to 140 lbs. It is not, however, implied that heavy work should be done in this manner.

Bolton W. De Courcy, M. Am. Soc. C. E.—The complete success of the means and plan prepared by the authors and so well described by them makes a very interesting paper. Mr. DeCourcy.

Mr. DeCourcy. It is a mistake not to have a strict examination of all materials before they are sent from the factory. A contractor is very often put to great inconvenience by inspection on the ground. Without packing it is very difficult to make a perfectly tight joint at such severe pressure as the tests required. It is unnecessary to exceed the normal pressure so extremely as in the work mentioned in the paper; in fact, it might be detrimental.

There is a good recommendation for our western timber in the reference to the length of the timbers used in the cradle, 100 ft. The Pacific slope is certainly favored in the size and quality of its forest trees. The company represented by the authors is to be congratulated on every difficulty being so well met; and in the short time for the completion of the work governed by the phenomena of the river and also unseasonable rain, proof is presented of completeness of design, as well as pluck, energy and ability.

Mr. LeConte. L. J. LeConte, M. Am. Soc. C. E.—The ball joint adopted is of excellent design in many respects, but rather too expensive for common

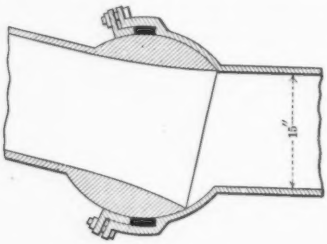


Fig. 6.

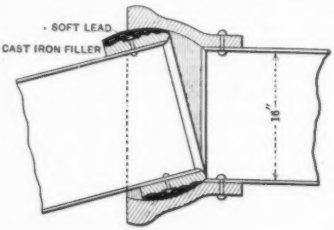


Fig. 7.

use, there being too much nice turning required. The most useful ball joints of to-day are but modifications of the old ball-and-socket or universal joint invented by Mr. James Watt for the Glasgow Water-Works Company in 1810, which laid in that year an inverted siphon 1 000 ft. in length across the River Clyde. This was of cast-iron 15 ins. diameter in 9-ft. lengths with flange joints, and had ball joints interposed at variable distances, depending upon the profile of the bottom of the trench. The length of the sections between ball joints was generally 28 ft. 6 ins., except at the middle of the line, where a single 10-ft. length became necessary in order to fit the ground. The ball surfaces were not turned at all, being made watertight by means of an adjustable packing joint similar to an ordinary stuffing-box.

The details of Watt's 15-in. siphon ball joint are shown in Fig. 6. This pipe line was laid on strong frames, made of parallel logs; these frames were joined by strong iron hinges, having their pivots in hori-

zontal lines at right angles to the axes of the pipes and passing through the centers of spheres, of which the zones of the sockets are portions. The flexible joints are at the extremities of the frames. The frames and pipes were put together in succession on ways situated on the south side of the river, and, the open or north end being plugged, were hauled into and across the bed in a trench prepared for them. The hauling machinery was, of course, on the north bank. The operation was quite simple, being aided by the flotation of the framework and the buoyancy of the empty siphon, assisted and directed by pontoons. The movable joints and hinges of the frames allowed them to conform to the bed. Mr. LeConte.

The water company put in another siphon, 18 ins. in diameter, in 1830; a third siphon, 25 ins. diameter, in 1838, and a fourth siphon, 40 ins. diameter, in 1840. All of these were put in under the same plans.*

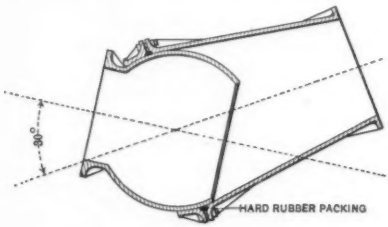


FIG. 8.

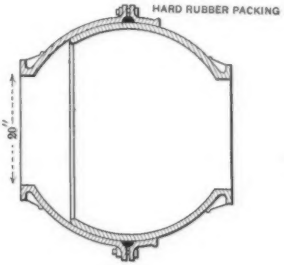


FIG. 9.

The longitudinal "pull" mentioned by the authors always exists more or less and invariably tends to tighten the ball joints. In case of wrought iron and steel pipe this "pull" is also partly due to swelling of the pipe under high pressure. In extreme cases the shortening of the pipe line is quite marked.

Leakage at the top of the ball joint under low pressure is almost universally the case with the larger sizes; but if the joints are made with ordinary care, high pressure (60 lbs. say) is ample to force the balls back to their bearings and thus stop leaks due simply to slight looseness in the socket or packing.

The device adopted for laying the pipe line was admirable, and an improvement on that used by the Spring Valley Water Company, of San Francisco, Cal., in laying a double line of 16-in. pipe across the upper part of San Francisco Bay. This double siphon was 16 000 ft. long, the depth of water being 50 to 60 ft., with strong tidal

* See "The Life of James Watt," by M. Arago, 1833.
"History of the Water Supply to Glasgow," by John Burnet, 1869.

Mr. LeConte. cross-currents and at times some very heavy seas. The ball joint adopted for this work is shown in Fig. 7, and was very cheap and efficient.

Where the siphon is subjected to sharp bends, a good deal of head is lost by friction at the ball joints. This difficulty is greatly relieved by the modification introduced in the Badois joint (Fig. 8), in which the rear portion of the socket or casing is made in the form of a long frustum of a cone. This reduces friction very much. The von Schmidt joint is shown in Fig. 9.

Mr. Schuyler. JAMES D. SCHUYLER, M. Am. Soc. C. E.—In June, 1893, the writer was called upon to make a report to the Water Committee of the city of Portland, on the subject of the most desirable method of effecting the crossing of the Willamette River with the pipe which forms the subject of this paper, and was engaged in planning and constructing the system of distributing reservoirs in connection with the same plant at the time the work of laying the pipe was performed. The first examination, to which two weeks were devoted, demonstrated that considering the elements of time and cost of governing, no other method of effecting the crossing of the river was practicable, but to lay a flexible-joint submerged pipe under the river-bed. The possibility was contemplated of using one of the four existing bridges spanning the river to carry the pipe, submerging it only at the short draw span, but as none of them had been designed to carry such an extra load the plan was manifestly impracticable. But for the lack of time to organize and combine with the city and county for the purpose of constructing jointly a new bridge designed for the purpose, and located about 1 mile up the river from the highest existing bridge, where high bluff banks admit of erecting a bridge high enough to clear river craft at all stages of water, that plan of crossing would have appeared the most desirable. The pipe would then have been accessible at all times, and the ordinary cast or wrought iron pipe could have been used, while the maximum pressure might have been reduced some 40 lbs. per square inch by having the entire pipe nearer the hydraulic grade line. This plan not being feasible, the submerged pipe laid in a trench to be dredged some 12 ft. deep in the river-bed was the one recommended, substantially as previously planned, but with the following modifications of the plans :

First.—The diameter of the river section was reduced to 28 ins., or if two pipes were considered desirable as a measure of precaution, both were to be 28 ins. in diameter, but laid 100 ft. apart, that the breaking of one might not undermine and destroy the other.

Second.—The total length of flexible pipe was shortened by laying it only to the low water-line on each side instead of to the high water-line, thus effecting a considerable saving in distance of the more expensive pipe.

Third.—The pipe was to be made of wrought steel, with butt joints on the longitudinal seams, and cast-iron ball and socket joints. The balls were to be turned and fitted in the shop, joints poured and one end riveted, the work in the field to be only the riveting of the other end. Bids were to be taken also on aluminum bronze ball and socket joints. Mr. Schuyler.

Fourth.—The location of the crossing was to be changed from Clay Street to a line extending from the foot of Stephen Street on the east side to the foot of Mill Street on the west side, which location is 500 to 800 ft. higher up the stream.

Fifth.—Y branches and valves were to be placed on the main at some convenient points above high water-mark on each side of the river, for connection with a second pipe to be laid either across a high bridge, if such be built, or under the river, 100 ft. away from the first pipe.

The reasons given for these recommendations, which were accepted by the Chief Engineer, and adopted by the Committee upon his report, were in substance as follows: The reduction in diameter from 33 ins., which had been fixed upon for the diameter of a single line of pipe subsequent to the rejection of bids upon a double line of 24-in. pipe, was recommended because it could be accomplished without materially affecting the capacity of the main, and for the reason that without changing the thickness of the metal the strength could be increased in the ratio of 7 to 6, and the weight reduced 10 to 12%, enabling the pipe to be handled with greater facility and reducing the chances of accident. The capacity of the main to the high-service reservoir was computed at 22 325 000 galls. daily, in full section throughout, or 21 800 000 galls. with the submerged section reduced to 28 ins., while if delivery were made at the low-service reservoir direct, where at least 85% of the West Side water was to go ultimately, the capacity, even with the reduction in diameter at the river, would be about 28 400 000 galls. daily, which is greater by 3 000 000 galls. than the entire capacity of the Bull Run pipe, which has to supply both sides of the river. The only reason for the delivery of the low-service water through the high-service reservoir on the West Side, is to utilize the power afforded by the drop from high to low service for pumping a small supply to levels 500 to 600 ft. higher, which power can at any time be replaced by steam, and the pipes left to deliver their utmost capacity where it may be needed regardless of the power question.

The preference given to wrought steel over cast-iron was chiefly on account of the longer lengths and fewer joints with which it might be laid, and under the supposition that 13 ft. was about the longest length at which cast-iron pipe was ordinarily made. The contractors succeeded in obtaining cast-iron pipe in 17-ft. lengths, which reduced the number of joints supposed to be necessary by 23 per cent.

Mr. Schuyler.

The change in location was recommended because it was manifestly a better line in many respects, with a more uniform and firmer bottom, with coarser gravel, less liable to scour, requiring less dredging for the pipe-trench, having better approaches, beside being somewhat shorter.

Specifications were prepared in accordance with these recommendations, but calling for bids on cast-iron pipe in addition to the steel pipe, the result of which was that the lowest tenders for cast-iron being about $14 000 less than the lowest bids for riveted steel, the cast-iron was given preference, chiefly, if not solely, on economic grounds.

The bids for steel pipe ranged from $68 000 to $164 640, the latter being the bid for aluminum-bronze ball and socket joints with steel butt-joint riveted pipe. For cast-iron the bids ranged from $54 000 to $113 580. The prices asked for laying varied from $2 50 to $19 per foot. The increased cost due to the revision of the bid of the Oregon Bridge Company referred to in the paper, amounted to about $13 000, and this and some extras brought the total cost of the submerged pipe, 2 000 ft. in length, up to $79 885.

The saving to the city which can be directly traced to the recommendations of the Consulting Engineer on the basis of the contract prices, amount to about $40 000 over the double line of 24-in. pipe which had been contemplated, or about $25 000 over the single line of 33-in. pipe, a circumstance which is referred to without any desire to claim any special merit or achievement, but as indicating the value of calling an outside engineer in consultation, one who can view local conditions with new eyes and from a different standpoint.

The successful laying of this pipe under numerous difficulties was a creditable piece of work, and the mechanical appliances employed were ingenious and well planned. The cradle on which the pipes were laid while the joints were being poured, and down which they slid to the bottom on a true 10° curve, was specially applicable to the conditions of this case, although in rougher waters or with depths over 40 to 45 ft., such a cradle would be too severely strained to be practicable.

The authors refer to the fact that during the experimental tests of the first joints laid out from shore "the leakage was in every case confined almost entirely to the upper portion of the joint, the extreme lower portion being tight," and suggest that this was the result of the extreme weight of the pipe, "which the most accurate workmanship could not overcome." As the surface area of the lead in the lower half of the pipe is about 592 sq. ins., the weight of the pipe when lifted 4 ft. at one end might produce a compression of the lead to the extent of about 0.008 in., which would leave a space sufficient to account for considerable leakage, provided the pipe rested in lead alone; but, unfortunately for that theory, the projecting flange or ring of cast-iron inside the bell, which forms the back wall for the lead in the joint (see Fig. 1, page 258), acts as a rest and a centering ring for the spigot end

of the male pipe, and would prevent any such compression in the lead, or any perceptible compression whatever. For this reason it seems that the chief cause of the leakage at the top of the joint, which was observed before as well as after the pipe had been raised and lowered, arose from sponginess in the lead, due to confined air in the lead space, caught during the pour without sufficient vent or escape, as well as to insufficient calking, due to the great depth of the lead. Mr. Schuyler.

The method adopted of pulling the joints tight by bolting on a head or flange and subjecting it to very high pressure at intervals of about 200 ft. during the process of laying was so palpably effective that it overcame all objections raised to the roughness of the turning of the balls. The pressure was sufficient to produce a more perfect calking of the lead than would have been effected by any other available means.

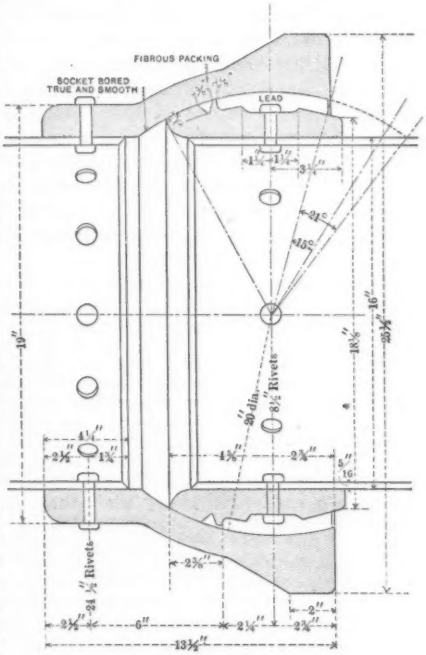


FIG. 10.

The question raised by the paper is as to whether this is a customary or desirable method of procedure in laying submerged pipes, and also as to whether greater perfection in turning is not ordinarily sought and attained than was given to the balls in this case. The double line of 16-in. pipe laid by the Risdon Iron and Locomotive Works, in 1887, for the Spring Valley Water Company of San Francisco, across the Bay of San Francisco, was made with joints so perfect that when tested in the shop, under pressure as high as 500 lbs. per square inch, and turned at all angles with the pressure off and on alternately, no leakage whatever was observable; hence it was not necessary to resort to pulling on the joints, by using high pressure at frequent intervals while laying, to make them tight after laying. In this joint hemp packing was used, and to its use much of the excel-

Mr. Schuyler. lence of the joint has been attributed. The construction and laying of this pipe is described in a paper* by R. S. Moore, Superintendent of the Risdon Iron and Locomotive Works, from which the following facts have been gleaned: The distance from shore to shore was 6 500 ft., of which 2 000 ft. in the center was from 50 to 60 ft. in depth. During the laying they experienced much rough weather, and at all times had to contend with a tidal current that was often as strong as 6 miles an hour. The motion of the vessel during time of high winds was occasionally so great as to prevent the pouring of the joints, and to compel the workmen to suspend work until the weather moderated.

The barge from which the pipes were laid was held in place by taut cables, anchors and a firm lashing to the pipes, that were suspended always slightly above the shute where the pipes entered the water. No divers were employed, nor was the pipe pulled at all by applying pressure. (At Portland a diver was constantly employed calking joints under water.) Both pipes were laid simultaneously, side by side, in lengths of 18 to 19 ft., and consisted of lap-welded tube, galvanized or "kalameined," and double dipped in asphalt, the joints being made in cast iron, riveted to the tube (see Fig. 10).

The author of the paper quoted, in a recent letter in reply to an inquiry, writes as follows:

"Our idea in designing this joint was to have one which would permit of sufficient deflection while the pipe was being laid, and which would be absolutely tight when the pipes were straightened out on the bottom of the bay. The joints we used accomplished this purpose to our entire satisfaction, and we were, therefore, not compelled to resort to the method used at Portland of pressuring the pipe in order to make it tight. The writer thinks it would have been impracticable to have put pressure on any of the Spring Valley pipe during the time it was being laid. The effect of doing so would be to set all the joints, including those in suspension from the barge, as well as those on the bottom of the bay. This should not be done. From the papers received it would seem that the method pursued by the contractors at Portland has accomplished the purpose intended, but we would not nor could not adopt this method if we were laying another pipe across the Bay of San Francisco, or across any other water where it was rough or deep; and while we think the joints of the Portland pipe could have been made tight enough by accurate workmanship, still the results obtained by the use of pressure accomplished the same desired end, in that particular case, at much less expense, and in a manner that should be just as permanent."

The occasion of the controversy between the Chief Engineer and the contractors, referred to in the paper, was occasioned, in a word, by the fact that the latter chose what was considered by the former a novel method of making the pipes tight. When the pipe was designed it was never intended to be made tight in any other way than by such close and accurate workmanship in turning as would leave it tight after bending the joints at any time and in any way desired.

* See the *Transactions* of the Institution of Engineers and Shipbuilders in Scotland, Vol. XXXI, p. 207.

Therefore, the proposition to make leaky joints tight by pulling on them after they were laid was only acceptable under stress of compulsion to avoid an impending crisis, as a few weeks of delay at that time meant the postponement for another season of the completion of the entire plant, with its attendant expense for pumping and interest, amounting to more than the contract price of the submerged pipe in controversy. Mr. Schuyler.

FRANKLIN RIFFLE and ALBERT S. RIFFLE, Members Am. Soc. C. E. —The authors would preface their closing remarks with a brief account of a later test than the one described in their paper. This test was made during the night of February 20th, 1895, three months after the completion of the work and two days prior to its acceptance. As the authors were not given an opportunity to be present, they were compelled to avail themselves of information kindly furnished them some days later by one of the assistant engineers who had been detailed by the Chief Engineer to test the pipe line. When the gates were closed, the gauge in the gate-chamber recorded a pressure of 120 lbs. After about six or eight strokes of the hand pump connected with the pipe line, the engineer directed his lantern to the gauge and was much surprised to find that it recorded a pressure of 150 lbs. As his instructions had been not to exceed the working pressure, 140 lbs., the pump was stopped until the pressure receded 10 lbs. It was then found necessary to pump 5 galls. of water into the pipe line to hold the gauge at 140 lbs. for a period of 12 minutes. The apparent leakage was, therefore, less than $\frac{1}{2}$ gall. per minute. The engineer, however, assumed that the gates leaked the same amount as when the previous test was made, viz., $\frac{1}{4}$ gall. per minute. As the pump, also, was in a leaky condition, he was forced to the conclusion that the line was practically tight, and so reported to the Chief Engineer. Messrs. F. and A. S. Riffle.

The authors had hoped the discussion would bring out some important facts relative to the method of casting ball and socket pipe, reference to which was inadvertently omitted in preparing the paper. Both Mr. Kuichling and Mr. Duane emphasized the importance of reinforcing the socket, owing to the danger of fracture arising from tensile strains. In this connection, the fact should not be ignored that the quality of the metal in the bell or socket is sometimes much inferior to that in any other portion of the pipe, owing to the practice of some manufacturers to cast the bell end uppermost. This practice should be condemned, since the saving in cost scarcely cuts a figure in the matter. However conscientious and painstaking a manufacturer may be, impurities will rise to the top and become a portion of the shell. While the presence of slag and sand, and numerous blow-holes adroitly filled with a combination of iron filings, sal ammoniac and flowers of sulphur, concealed from view by the usual preservative, may escape the eye of the inspector, such imperfections are hardly consistent with what is generally understood by a "good gray casting."

Messrs. F. and A. S. Riffle.

While an imperfect casting of this description might pass the usual hydraulic test, such a test would furnish no guarantee that it would successfully withstand great radial strains due to the wedging of the ball in the socket; hence, the importance of having the best metal instead of the poorest in the socket. This could be accomplished by reversing the usual practice of casting, in which case the impurities would rise to the last few inches of the ball, which is subjected to neither radial or longitudinal stresses when in place, and being confined to that portion of the ball which is outside the limit of flexure, the rough surface, due to slag or blow-holes, should such exist after machining, would not come in contact with the lead. While there may be some doubt whether a truly spherical and smoothly finished ball will require a longitudinal pull to secure a water-tight joint, it should, nevertheless, be borne in mind that conditions are always likely to exist when pipes are laid in the bottom of a stream, such as settlement or undermining, which may impose an equal amount of longitudinal strain. In view of these facts, the suggestion of Mr. Kuichling that the socket be reinforced by a band of wrought iron or steel is an excellent one. Mr. Duane's method of reinforcement is immeasurably superior to that used at Portland, for reasons which will appear later on.

The criticism of Mr. Tribus that the exact cost of the work was not given has been satisfactorily answered by Mr. Croes, and the data contained in the paper are sufficient for an engineer to make a reasonably close estimate of the cost of work to be done under similar conditions.

As Messrs. Emery and Gould stated, perfect lathe work is always preferable to imperfect work, and with the requisite amount of care "it is just as easy to turn the joints perfectly true as not to do so." However, the slight inaccuracies noted were not sufficient grounds for rejecting the pipes at the risk of delaying the completion of the water system for a period of one year, not to mention the palpable injustice of such a proceeding to the contractors, who had from the first acted only in good faith, relying solely upon the shop inspector appointed by the Chief Engineer. It was pleasing to note that an engineer of such wide experience and reputation as Mr. Duane had taken the same position. The latter's statement based on experience, that the tightness of flexible joints is "dependent upon their being laid on their final bed under a strong tensile strain" is of great value, since it establishes the fact that, while it may be possible to secure tight flexible joints without this "tensile strain," under certain favorable conditions, such as light pipes and perfectly turned joints, the method of laying the pipes under tension insures absolute success under any and all conditions.

Concerning Mr. Ward's remarks, it should be said that in describing their method of laying submerged pipes the authors gave no thought as to whether the method was original with them or not,

Messrs. F. and A. S. Riffle.

although at the time they prepared the plans for the cradle they had neither seen nor heard of a similar contrivance. Some time afterward, however, their attention was called to an illustration of an inclined plane used in laying a 24½-in. steel riveted pipe, with flexible joints, across the River Maas in Holland. This device differed from the one designed by the authors principally in two respects, viz., there was no provision made for a change in the depth of water, and the slide being an inclined plane, admitted of no deflection at the joints until the pipes reached the bottom, thus necessitating a very long and unwieldy contrivance.

Mr. Ward's deductions relative to the static friction of the pipes on the bottom of the trench are incorrect, since no allowance was made for the action of gravity. The 650 lin. ft. of pipes tested to 250 lbs. per square inch were on a descending grade, 190 lin. ft. being on a 12½% grade, and the remaining 460 lin. ft. being on a grade of about 5½ per cent. Mr. Ward assumed that the total force of 250 lbs. per square inch was exerted to overcome the static friction of the pipes on their bed, which was not the case. While it was quite evident that a large percentage of the applied force was necessary to start the lead in the large end of the reducer, the exact amount could only be a matter of conjecture. A more reliable frictional coefficient might be obtained from the experimental test of the first eight pipes laid, six of which lay level in the trench previous to its excavation below the water-line, the last two lying on a grade of 12½ per cent. During this test the joints gradually tightened in succession from the free end toward the reducer, the leakage at the last flexible joint diminishing quite perceptibly at a pressure of 35 lbs., and the joint becoming absolutely tight at a pressure of 45 lbs. per square inch. The former, then, would represent the force required to overcome the static friction of the pipes. The coefficient of friction was, therefore, about 0.27.

The statement that "the advantages in favor of the long pipes are obvious," concerning which Mr. Duane raised some questions, was intended to refer more particularly to the reduced cost of construction, as well as to the fact that the reduced number of joints, each liable to either vertical or horizontal deflection, or both, would offer less resistance to the flow of water. A long pipe will bridge over the inequalities which exist necessarily in a dredged trench. These soon become filled up by the action of the current. Such was the case with this particular line, portions of which were half buried at the time of completion. For this reason there was not the same necessity for using short lengths as in the case of the "irregular rocky bottom" of East River in the vicinity of Blackwell's Island. The use of short joints for facilitating repairs would, however, be quite advantageous.

Mr. Duane's questions are answered as follows:

First.—The lead was poured and calked in two separate operations, as described by Mr. Fanning.

Messrs. F. and A. S. Riffle.

Second.—The rib, which served as a lead stop, answered the purpose admirably, making the use of yarn unnecessary.

Third.—The pourings were made from a kettle, suspended over the joint by the derrick used for handling the pipes, and having an orifice in the bottom, which could be quickly opened or closed by means of a vertical screw. The lead should be run at one pouring, and calking was unnecessary; but as the work was done under the supervision of the Chief Engineer, the authors had no option in the matter.

The answer to Mr. Dunham's remarks is that the cradle was employed for the purpose of supporting the pipes until they reached the bottom of the trench, thereby avoiding excessive strains on the sockets, which would have occurred had the pipes been merely suspended from the pipe-laying barge. Owing to the great weights of the pipes the latter method would not only have resulted in straining the sockets at the risk of cracking them, but would also have had the effect of wedging the shoulders of the ball ends tightly against the collars, so that the joints would have become inflexible, and many would, no doubt, have refused to accommodate themselves to the bottom of the trench.

The following were the probable reasons of the Chief Engineer for deciding upon the use of flexible joints:

First.—The pipes could be laid without obstructing navigation.

Second.—They would readily conform to irregularities in the bottom of the trench.

Third.—In the event of possible shifting of the channel during freshets there would be far less danger of leakage or rupture. As this is a portion of the main-pipe line which supplies the city of Portland with water, the Chief Engineer was expected to take every reasonable precaution against accidents which would tend to shut off the water supply.

Mr. Dunham's query, "Why was the integrity of an important line left dependent upon the threads of 1-in. iron bolts and nuts which may be exposed in the river bottom to corrosive substances," opens up an interesting question relative to this design of the joint, and suggests radical defects which were fully confirmed by experience. A collar, if used at all, should not be cast in sections. A glance at the sketch of this joint (see Fig. 1, page 258), will plainly show the weakness of the collar at the connections, where two thin lugs of cast-iron are subjected to great bending moments, the result of radial stresses in the collar. It is apparent that these lugs are wholly inadequate to withstand the stresses that must necessarily come upon them when the line is subjected to tension. As a matter of fact, some of the lugs were broken by calking alone, others by bolting (although the greatest care was exercised to avoid undue strains), while many were broken during testing, the fractures always occurring at the connections. Whenever a fracture occurred while testing, a muffled sound could be heard on the barges accompanied by a perceptible movement of the pipe. In the gate chamber the reports due to the breaking of the lugs were greatly in-

tensified, and on several occasions had the effect of speedily expelling the occupants. Messrs. F. and A. S. Riffle.

The proper endwise strain or pull upon the submerged line could not be continued after the connection was made with the larger pipe at the completed end. This was not essential, since the joints were pulled tight before the connection was made.

In reply to Mr. DeCourcy, it is to be said that the Chief Inspector of the Water Committee predicted that it would be an absolute impossibility to make the joints tight without the use of hemp packing, and that in deference to his recommendation the Chief Engineer authorized the contractors to use a packing of some sort before pouring the lead. They, however, being firmly convinced of their ability to make the joints tight with lead alone, and not wishing to give an opportunity for raising the question that the joints would remain tight only until the packing decayed, declined to take advantage of this concession. The result has clearly demonstrated the wisdom of their course.

While it was unnecessary to exceed the normal pressure so extremely, the fact should not be lost sight of, that the contractors were compelled to make the joints, not only practically, but absolutely, tight, or run the risk of not having the work accepted upon its completion.

Mr. Schuyler's eminent services as Consulting Engineer of the Portland Water Works, particularly as designer and engineer of the four large distributing reservoirs, certainly justifies the very modest reference to himself. Passing over the historic portion of the discussion, which is undoubtedly correct, the authors desire to correct an error in reference to the curvature of the cradle which Mr. Schuyler describes as a "true 10° curve." The degree of curvature was about 61¼°, while the axial deflection of the pipe was 10°.

Mr. Schuyler's position in refusing to admit the possibility of compression in the lead, due to the increased weight of the pipe when raised, owing to the back lead stop, is untenable, inasmuch as this small run, like all the rest of the metal, was covered with a coat of asphaltum paint. That this coating would sustain such a weight, especially after being heated to a liquid condition by the hot lead, is hardly probable. It is, then, safe to assume that it offered but little resistance to compression or abrasion during rotation. When pipe-laying began from the cradle, this coating was removed from the back lead stop, as well as from the interior of the bell covered by the lead. In stating that "the leakage at the top of the pipes was observed before as well as after the pipes had been lowered," he has been misinformed. As these experiments were conducted solely for the benefit of the Chief Engineer, the work was done to suit his inspector, who insisted that each length should be raised and then lowered, as laid. Only the last of the eight lengths was allowed to remain as calked, at the special request of the contractors. A test of these eight lengths was then made, the leakage in the last joint being very small, but not

Messrs. F. and A. S. Riffle.

confined to any particular portion of the run. Mr. Schuyler advanced at the time the same opinion expressed in his discussion, viz., that the leakage arose from "sponginess in the lead due to confined air in the lead space," and recommended drilling a hole in the uppermost portion of the bell, to permit the escape of air. The contractors could not at the time, neither do the authors now, in the light of subsequent events, accept the suggestions offered as a conclusive solution of the difficulty.

The pouring vent was at all times sufficiently large to permit the free escape of air, and an air space in the extreme upper part of the bell was only possible when the pipes were not sufficiently inclined to permit a free escape. In laying from the cradle, the great angle of inclination precluded any possibility of confined air. The position taken by the contractors in this matter was fully confirmed in an examination of the lead removed from the two broken sections of pipe on the west bank, both joints of which were poured while the pipe was in a horizontal position. The lead presented a perfectly homogeneous appearance throughout, with no sign of air obstruction, even in the topmost portion. The effect of the calking did not extend noticeably beyond $1\frac{1}{2}$ ins. in depth, which is usual for lead calking.

Mr. Schuyler's description of the double line of 16-in. pipe across San Francisco Bay for the Spring Valley Water Company is very interesting, but would be decidedly more so and of greater value had he pursued his inquiries further and obtained some definite and accurate data concerning the tightness of the line after completion. His reference to the excellent result of the shop test deserves notice. A description of the method employed in conducting that test would have been of great interest, especially the means adopted to prevent calking by hydraulic pressure. His silence upon that point, coupled with the statement that the pipe was revolved during test, carries with it the suspicion that the test was identically the same as that adopted by the authors.

He states that "at Portland a diver was continually employed calking joints under water." This statement is incorrect, as may be seen by a careful perusal of the paper, which says that "little calking under water was necessary, however, the joints being practically tight from first to last." The amount of calking under water in the whole line would not exceed two or three hours of actual labor.

In closing his discussion, Mr. Schuyler states that it was never intended to make the pipe line tight "in any other way than by such close and accurate workmanship in turning as would leave it tight after bending the joints at any time and in any way desired." He must have known, in virtue of his position as Consulting Engineer, that the specifications were decidedly lacking in reference to the points at issue. That the method finally adopted by the contractors to secure good results was not novel, as stated by Mr. Schuyler, has been fully established by this discussion.

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SPECIFICATIONS FOR STRUCTURAL STEEL.

By H. H. CAMPBELL, M. Am. Soc. C. E.

READ APRIL 3D, 1895.

WITH DISCUSSION.

In the consideration of a specification for structural steel there are three fundamental subdivisions.

First.—The method of manufacture.

Second.—The chemical composition.

Third.—The physical properties.

Some engineers are content with testing the finished material, claiming that it is the province of the manufacturer to obtain the required properties by any method he may choose.

Others prescribe a chemical formula or set maxima for certain elements and let the maker do as he will in reaching the result. Still others go to the root of the matter and specify in just what kind of a furnace the steel shall be made, just how that furnace shall be lined, just what stock shall be charged, and just what size ingots shall be cast.

The following pages will endeavor to show that the mode of manufacture and the composition of the metal should be laid down in the

contract, but that some of the latest specifications have carried the requirements in this direction as far as reason will allow, while there is room for great improvement in the determination of the physical properties.

I.—The Method of Manufacture.

It is a current impression among many engineers that the method by which steel is made can be found by making a chemical analysis. Let it be stated, therefore, that although certain experiments indicate a difference between Bessemer and open-hearth metal in the character of the occluded gases, this system of analysis is never resorted to in practice and no provision is made for it in laboratories. Moreover, it is doubtful if any expert would risk his reputation by asserting positively from any such evidence that a certain steel was made by either one or the other process. Aside from this occult and unused method it is certain that the ordinary systems of testing fail entirely to distinguish the product of the open-hearth furnace from that of the Bessemer converter. Notwithstanding this fact there is good testimony to show that the product of the converter is an inferior metal which gives way in a treacherous manner under shock. It is granted that in a strict sense there is no such thing as treachery or mystery, but these are convenient terms to cover an undiscovered law.

The evidence concerning the unreliability of Bessemer steel is made up, for the most part, of scattered individual opinions, many of which have been made on insufficient evidence, but they are too numerous to be entirely ignored and they are fortified by the carefully considered statements of men whose words are weighed and who are absolutely disinterested in their decisions. Thus Mr. A. E. Hunt, whose long experience as the chief of the Pittsburgh Testing Laboratory gives much force to his opinion, writes as follows :* "Numerous cases have come under our observation of angles and plates which broke off short in punching, but although makers of Bessemer steel claim that this is just as likely to occur in open-hearth metal, we have as yet never seen an instance of failure of this kind in open-hearth steel."

Mr. Hunt also quotes* from a paper by Mr. Wailes before the British Association to the effect that "these mysterious failures occur in steel of one class, viz., soft steel made by the Bessemer process." We have

* See the *Journal* of the Iron and Steel Institute, Vol. II, 1890, p. 316.

also the testimony of Mr. W. H. White, Director of Naval Construction, Royal Navy :* "With converter steel, riveted samples have given less average strength, greater variations in strength, and much more irregularity in modes of fracture than similar samples of open-hearth steel. The basic open-hearth metal has proven to be as good as that made on the acid open hearth, and after full investigation it will be used by the Admiralty in ship plates and boiler tubes on an equal footing."

It is acknowledged that the case is not yet closed, but until these statements are controverted by direct and positive evidence, the only safe way for the engineer is to prescribe that only open-hearth metal shall be used in all structures like railroad bridges, where the metal is under constant shock and where life and death are in the balance. And it should be emphasized that if this provision is incorporated, a careful watch should be kept for fraud, as there is no way in which a substitute can be detected. The objections to Bessemer steel are many times emphasized in the product of the basic converter, for at the end of the operation there is often a very considerable percentage of phosphorus that passes back from slag to metal, and which is not always uniformly distributed. This fact utterly condemns it for the best of work. This objection does not hold true with respect to the basic lined open-hearth furnace, for while a basic converter absolutely requires a high content of phosphorus in the iron and a correspondingly impure slag, and while the reaction during recarbonization in basic Bessemer practice is almost always violent, the basic-lined open hearth does not require a very impure iron, the slag is not necessarily impure, the reaction with the recarbonizer is not violent, and the amount of rephosphorization is almost inappreciable.

A very common argument against basic steel is that good steel cannot be made from bad stock. Unfortunately this statement is sustained by many so-called practical men who have no knowledge of any process which was not tested and proven in the days of their infancy. To a certain extent the thesis was once true, but from a broader point of view it has always been wrong. The finest acid steels, both open hearth and crucible, have long been made from washed pig iron, puddled iron or charcoal blooms, all produced by the application of a basic process to a more or less phosphoritic iron. If, then, the best steels are made by remelting the product of a basic hearth, it is not inherently im-

* See the *Journal* of the Iron and Steel Institute, Vol. I, 1892, p. 135.

possible that the product of a basic hearth may be cast directly into good steel. The basic open-hearth furnace has come to stay. It can not make common steel any cheaper than the acid process, but it can produce more economically a tough, ductile, pure metal which is fast finding its way into general use.

The careful engineer may conscientiously refuse to employ the new material, but let him acknowledge that his decision is an honest conservatism, and let him not lay down metallurgical laws concerning that which is outside his domain. The steel-makers of this country stand ready to supply either acid or basic open-hearth metal of any desired quality, but they ask of the engineer that the terms of the contract as to the method of manufacture be enforced, in order that a maker who bids on a certain lot of low-phosphorus acid steel may not be underbid by a competitor who trusts that he can obtain a concession and make it on a basic hearth. There is less cause for watchfulness in the case of steel containing over 0.08% of phosphorus, since such metal should not be used in structures exposed to shock, and since the basic hearth possesses little, if any, economy over the acid furnace in the manufacture of such material.

II.—The Chemical Composition.

It is generally recognized as both undesirable and impracticable to specify the complete formula for a steel of a given strength and ductility. Within certain limits the manufacturer should be permitted to use whatever he thinks will best meet the requirements. A too rigorous adherence to some good formula would effectually prevent the discovery of better alloys. Moreover it is plain that if steel is made strictly in accordance with the prescription, the responsibility of failure and loss must rest with the engineer and not with the maker. These propositions are so axiomatic that it may seem superfluous to recite them, but as a matter of fact it is a very common occurrence for the steel-maker to receive an order where almost every element is specified, together with an ultimate strength which is impossible under the conditions. Granting, therefore, as self-evident that a complete formula must not be prescribed, there remains to be considered how far it is advisable to define the chemical content of the separate elements.

Carbon.—In all the structural steels used to-day, a variation in strength is produced either in whole or in part by a variation in the

carbon content, and this metalloid is so competent to perform its functions, that a high metallurgical authority has declared that pure steel is pure iron plus pure carbon, and that all other elements are impurities. Leaving aside this ultra and widely disputed statement, there remains the fact that it is the main reliance of the steel-maker and that probably no other element can confer a given increase in strength with as little diminution in ductility and as little increase in brittleness under shock. It is, therefore, absurd to place any limit to the carbon content in a steel of a given ultimate strength, since a high percentage necessarily denotes a correspondingly low content of other metalloids.

Silicon.—The contradictory testimony concerning the effect of silicon on steel has been well summarized by Mr. Howe in his "Metallurgy of Steel," where many examples are recorded of exceptional steels with abnormal contents of silicon, and where the theories advanced by different writers are fully discussed. He finds no proof that silicon has any bad effect upon the ductility or toughness of steel, and argues that the bad quality of certain specimens is not necessarily due to the silicon content, but to other unknown conditions. A Bessemer steel with high silicon is sometimes produced by hot blowing, but it will be entirely wrong to compare such metal with the common product and ascribe all differences to the chemical formula rather than to the circumstances which created that formula.

Further experiments by Mr. Hadfield* show that steel may contain as much as 3.4% of silicon, with a tensile strength of 106 000 lbs. per square inch, and still register an elongation of 11.1% in a length of 2 ins. These results are of the highest value in showing that silicon cannot be classed among the highly injurious elements, for in similar proportion phosphorus and sulphur would be out of the question, manganese would give a worthless metal, and carbon would change the bar to pig iron. It will therefore be only reasonable to suppose that small quantities cannot exert a very deleterious influence.

It is well known that many continental works have habitually made their rails with from .30 to .60% of silicon and that all requirements of strength and ductility have been met. In fact, the author was told by the manager of one of the French establishments that the only way in which he was able to fill one contract, with particularly severe

*See the *Journal* of the Iron and Steel Institute, Vol. II, 1889.

specifications, was by making the steel from .30 to .40% in silicon, since a less proportion would not stand the drop tests. It is not necessary to question whether this conclusion was warranted or not; it is enough to know that the steel was of the best quality, whether on account of the silicon or in spite of it.

The fact that silicon may be allowed in rails has been acknowledged by Mr. Sandberg, who writes as follows:* "Silicon up to .30%, with carbon .30 to .40%, does not harden steel or make it brittle, and diminishes its strength in such small degree as not to imperil the safety of the rail." Exceptional cases have been recorded of soft steels with high silicon, like the very tough rail mentioned by Mr. Snelus,† with carbon below .10%, and silicon .83 per cent. It must be considered, however, that although this might have been very tough for a rail, it does not follow that it was very tough for soft steel, but it is quite certain that it could not have been bad or brittle.

With the knowledge possessed concerning the relative effect of impurities upon hard and soft steels, the assumption would almost be justified that low-carbon metal might be allowed to contain a larger percentage of silicon than higher steel. There is no need, however, of such an admission, for structural steels do not usually contain over .10% of silicon, while usually it is below .05 per cent.

Sulphur.—The prominent characteristic of sulphur is its power to make the steel crack and tear in hot working, and this affects the manufacturer rather than the engineer. The influence of this metalloid upon the cold properties has not been accurately determined, but it is quite certain that it is not very important. In common practice the content varies from .01 to .10%, and within these limits it seems to have no appreciable influence upon the elastic ratio, the elongation, or the reduction of area, and there is no evidence to indicate that it causes brittleness under shock. It follows, therefore, that no stringent specifications are necessary regarding this element as far as plates, angles and other shapes are concerned. In rivets, however, the case is different, for here the metal must be heated to a high temperature, and it is quite certain that sulphur will tend to create a coarse crystallization in the steel and thereby injure the strength and toughness of the joint.

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*See the *Proceedings* of the Institution of Mechanical Engineers, 1890, p. 301.

†See the *Journal* of the Iron and Steel Institute, Vol. II, 1882, p. 583.

Copper.—The remarks which have just been made about sulphur are also applicable to copper. It injures the rolling quality of the steel, but has no appreciable effect either upon the ultimate strength or ductility, and hence there is no occasion for the engineer to consider it, except in the case of rivets where an excessive content may cause the metal to be red-short. The effect of copper, however, unit for unit, is only a fraction of that which sulphur exercises. Hundreds of thousands of tons of excellent steel have been made containing over 0.5%, and millions of tons containing over 0.25 per cent.

The Pennsylvania Steel Works has probably had a far wider experience in the use of cupriferous metal for all grades of steel, both low and high, than any other works in the world, and we have yet to learn that it affects either the strength or the ductility of the finished material. It is not easy to make a comparison between high and low copper steels, for at works using such material it is customary to keep a fairly constant percentage in the mixture rather than to vary between wide limits. A few heats are shown in Table No. 1, and although the list is not as long as might be desired, it should be considered that the heats were all made within a short period in the same Bessemer, and were all rolled in the same mill :

TABLE No. 1.

COMPARATIVE PHYSICAL PROPERTIES OF LOW AND HIGH COPPER-STEEL ANGLES.

Thickness in inches.	Copper. Per cent.	Number of heats.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Elastic ratio.
⅞	.10	11	61 376	44 152	27.52	56.30	71.9
	.35	17	60 283	43 841	27.88	59.01	72.7
¾	.10	10	58 965	42 218	28.85	55.50	71.6
	.35	11	59 630	43 478	29.02	57.86	72.9

This limited investigation cannot prove conclusively that copper is beneficial, but it does indicate that this element has been unjustly

maligned. In view of the good quality of angles containing .35% of this impurity, it seems a trifle absurd to find a specification that sets the maximum at any such figure as .05 per cent. It must be kept in mind by engineers, that there is no way of eliminating copper in either an acid or basic furnace, and as a large percentage of the iron and the steel scrap east of the Allegheny Mountains contains a considerable proportion, the eastern manufacturer can avoid it only by buying selected material at a considerably increased cost.

Manganese.—Spiegel iron or ferro-manganese is added to a heat of steel at the time of tapping, in order that it may seize the oxygen which is dissolved in the bath and transfer it to the slag as oxide of manganese; but this reaction is not perfect, and there is reason to believe that all common steels contain a certain percentage of oxygen. It is a question whether this does any great harm, for it seems probable that some manganese would be necessary to make the steel work well, even if no oxygen were present. Steel low in phosphorus and sulphur requires less manganese than impure metal, although it is difficult to see why there should be less oxygen to counteract, and this indicates that the function of the manganese is to prevent the coarse crystallization which the impurities would otherwise induce. Besides conferring the quality of hot ductility, manganese also raises the critical temperature to which it is safe to heat the steel, for just as it resists the separation of the crystals in cooling from a liquid state, so it opposes their formation when a high thermal altitude augments the molecular mobility.

These two manifestations of the same general force render manganese one of the most valuable and essential factors in the making of steel, although there is no doubt that it has been used too freely in some cases. Years ago, some of the rail-makers of the country looked upon it as a panacea for all bad practices in the Bessemer department and rolling mill, and steel often contained from 1.25 to 2.00% of manganese, but it was soon discovered that such rails were brittle under shock, so that the permissible maximum has been gradually lowered, and the standard product of the present day contains from .60 to 1.00 per cent. In higher steels the same lesson has been learned, but in this case the necessity of a low content is far more marked, since a percentage which is perfectly harmless in unhardened steel will cause cracking if the metal be quenched in water. For this reason it is advisable to

reduce the proportion of this element in hard steel to the lowest possible point.

In structural metal there is no quenching to be done and the limit need not be placed too low, for the decrease in toughness due to an increase in the content of manganese is less marked than often supposed, as will be shown by Table No. 2. This is made by grouping together heats of the same character and about the same tensile strength, and separating them into two classes according to the manganese content. No arbitrary line is drawn between a high and low percentage, but each group is divided so that the number is as nearly equal as possible on each side. An unequal number is due solely to the fact that several heats may have exactly the same content, and these must all go either on one or the other side of the line.

It will be evident that there is no marked difference between the steels of high and low manganese, and the results of the eight different groups are so uniform in their testimony that the work of chance must be almost absent. These records of ductility, however, do not take into account the very important quality of resistance to shock. It has always been a problem to devise some way of applying a satisfactory test in this direction, but the method is yet to be found. A few crude experiments which the author performed on steel of high manganese to see how it would act under shock are given in Table No. 3. The bar was struck while in tension with a copper hammer, each blow being powerful enough to have bent the bar permanently, if it had not been continually straightened by the action of the machine. One of the effects of this hammering is to momentarily loosen the bar in the grips and make a sudden jar upon the piece. This action, coupled with the stress upon the outside fibers and the direct vibration, make the test quite exhaustive, although from the difficulty of measuring the force of impact it can hardly be called practical. Some of the bars were not struck until "failure," or until the maximum stress had been reached. This was on account of the trouble from slipping or jumping, above noted, which followed the hammering at earlier periods, and it was taken for granted that, if a bar would break at all from shock, the fracture would be likely to occur about the time when the piece was under destructive tension. It will be evident that the hammering did not in any case determine the time of breakage, for each piece gave as good an elongation and reduction of area as a part of the same rod which was pulled in the usual manner.

TABLE No. 2.

COMPARATIVE PHYSICAL PROPERTIES OF OPEN-HEARTH STEEL WITH DIFFERENT CONTENTS OF MANGANESE. MADE BY THE PENNSYLVANIA STEEL COMPANY.

Group.	Kind of steel.	Limits of ultimate strength in group. Pounds per square inch.	Phosphorus. Per cent.	Relative manganese.	Number of heats.	Manganese. Per cent.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Elastic ratio.	Shape of test.
I.	Acid.	55 000 to 60 000	.08	Low	7	.30	57 922	38 692	29.91	59.02	66.8	⅜" diam.
				High	6	.37	58 881	38 598	28.08	57.07	65.6	
II.	Basic	55 000 to 63 000	.03	Low	11	.44	58 005	38 547	30.16	60.21	66.5	2" × ⅜"
				High	11	.57	59 563	40 133	30.36	58.55	67.4	
III	Acid	60 000 to 65 000	.08	Low	16	.35	62 180	41 308	28.00	50.89	66.4	¾" diam.
				High	14	.51	62 605	41 169	27.65	54.66	65.8	
IV.	Acid	65 000 to 70 000	.08	Low	26	.51	67 421	43 923	25.96	51.29	65.1	¾" diam.
				High	32	.78	68 192	45 854	25.82	51.50	67.2	
V.	Acid	70 000 to 75 000	.08	Low	18	.60	72 353	46 836	24.23	47.79	64.7	¾" diam.
				High	25	.91	72 115	48 359	24.63	47.73	67.1	
VI.	Acid	75 000 to 80 000	.08	Low.	11	.65	77 520	49 411	22.34	44.42	63.7	¾" diam.
				High	11	.84	78 083	50 226	23.63	48.49	64.3	
VII.	Acid	80 000 to 85 000	.08	Low	9	.68	81 747	51 219	20.63	41.04	62.7	¾" diam.
				High	9	.82	81 860	52 231	22.67	47.75	63.8	
VIII.	Acid	85 000 to 90 000	.08	Low	5	.75	86 460	54 517	20.41	40.56	63.1	¾" diam.
				High	5	.83	88 034	55 409	20.66	41.92	62.9	

TABLE No. 3.

RESISTANCE TO SHOCK OF STEEL CONTAINING ABOUT 1.00 PER CENT. OF MANGANESE. MADE BY THE PENNSYLVANIA STEEL COMPANY.

(All tests ¾-in. rolled rounds.)

Heat number.	Manganese. Per cent.	Conditions under which test was made.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
6960..	1.00	Average of two tests; pulled quietly	71 040	47 055	25.87	55.05
		Average of two; hammered from start to finish	70 770	46 380	26.12	61.40
6961..	1.03	Average of two tests; pulled quietly	72 175	48 075	27.00	54.98
		Average of two; hammered from start to finish	71 120	47 330	26.00	59 20
6962..	0.94	Average of two tests; pulled quietly	74 020	48 165	25.62	52.60
		Average of two; hammered from start to finish	74 490	48 340	23.50	55.70
6963..	1.13	One bar; pulled quietly	81 070	52 880	22.50	43.60
		One bar; hammered from elastic limit to fracture	80 460	52 760	23.50	48.30
		One bar; hammered from failure to fracture.	78 050	51 800	19.25	55.30
		One bar; began hammering at 72 000 lbs., and moved scale weight back as the bar weakened	69 040	52 760	21.00	47.80
6981..	0.82	One bar; pulled quietly	67 340	46 030	28.12	55.00
		One bar; hammered from failure to fracture.	65 940	44 430	28.00	57.90
6982..	0.91	One bar; pulled quietly	66 700	46 310	26.00	55.93
		One bar; hammered from failure to fracture.	67 240	46 090	31.25	55.60
6983..	1.03	One bar; pulled quietly	69 700	47 650	26.00	51.70
		One bar; hammered from failure to fracture.	70 080	46 360	27.12	53.70

Phosphorus.—Of all the elements that are commonly found in steel, phosphorus stands pre-eminent as the most undesirable. It is objectionable in the rolling mill, for it tends to produce coarse crystallization, and, hence, lowers the temperature to which it is safe to heat the steel. For this reason phosphoritic metal should be finished at a lower temperature than pure steel, in order to prevent the formation of a crystalline structure during the cooling. Aside from these considerations its influence is not felt in a marked degree in the rolling mill, for it has no disastrous effect upon the toughness of red-short metal when the content does not exceed .15 per cent. The action of phosphorus upon the finished material may not be dismissed in so few

words. Mr. Howe* has gathered together the observations of different investigators, and the evidence seems to prove that the tensile strength is increased by each increment of phosphorus up to a content of .12%, but that beyond this point the metal is weakened. Whether this last observation be correct or not is of little practical importance, for it would be criminal to use a metal for structural purposes that contained an average of .12% phosphorus. Below this point the author is absolutely certain that phosphorus strengthens low steels, both acid and basic, and he believes that it has about the same power in this direction as carbon, unit for unit. The same certainty does not pertain to any other effect of this metalloid.

Mr. Howe has ably discussed the whole matter,* and quotations are herewith made from his "Metallurgy of Steel," and condensed in the form of a summary.

First.—The effect of phosphorus on the elastic ratio, as on elongation and contraction, is very capricious.

Second.—Phosphoric steels are liable to break under very high tensile stress if suddenly or vibratorily applied.

Third.—Phosphorus diminishes the ductility of steel under a gradually applied load, as measured by its elongation, contraction and elastic ratio, when ruptured in an ordinary testing machine; but it diminishes its toughness under shock to a still greater degree, and this it is that unfits phosphoric steels for most purposes.

Fourth.—The effect of phosphorus on static ductility appears to be very capricious, for we find many cases of highly phosphoric steel which show excellent elongation, contraction, and even fair elastic ratio, while side by side with them are others produced under apparently identical conditions, but statically brittle.

Fifth.—If any relation between composition and physical properties is established by experience, it is that of phosphorus in making steel brittle under shock; and it appears reasonably certain, though exact data sufficing to demonstrate it are not at hand, that phosphoric steels are liable to be very brittle under shock, even though they may be tolerably ductile statically. The effects of phosphorus on shock-resisting power, though probably more constant than its effects on static ductility, are still decidedly capricious.

The slight effect of phosphorus upon static ductility will be shown

*The Metallurgy of Steel, p. 67 *et seq.*

by Table No. 4, which is constructed by comparing the acid open-hearth angles in Table No. 11, which are of the same ultimate strength and of the same thickness, but contain different percentages of phosphorus.

TABLE No. 4.

Comparative Physical Properties of Low-Phosphorus and High-Phosphorus Steels.

Comparison of the acid open-hearth angles given in Table No. 11, which are of the same ultimate strength and of the same thickness, but with different contents of phosphorus.

Limits of ultimate strength. Pounds per square inch.	Number of group.	Thickness of angle. Inches.	Phosphorus. Per cent.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Average elastic ratio. Per cent.	Average elongation in 8 ins. Per cent.	Average reduction of area. Per cent.
56 000 to 64 000..	I	$\frac{15}{16}$ to $\frac{3}{8}$	0.05 to 0.07	60 443	40 929	67.72	28.66	58.52
			0.07 to 0.10	60 064	41 143	68.50	28.82	58.35
	II	$\frac{7}{16}$ to $\frac{1}{2}$	0.05 to 0.07	61 173	40 164	65.66	28.72	55.73
			0.07 to 0.10	60 583	40 170	66.30	29.05	56.30
	III	$\frac{9}{16}$ to $\frac{5}{8}$	0.05 to 0.07	61 318	39 548	64.50	28.31	52.92
			0.07 to 0.10	61 049	39 656	64.96	28.98	54.81
	IV	$\frac{11}{16}$ to $\frac{3}{4}$	0.05 to 0.07	60 609	38 559	63.63	28.62	50.09
			0.07 to 0.10	59 763	38 338	64.15	29.60	55.33
64 000 to 72 000..	V	$\frac{5}{16}$ to $\frac{3}{8}$	0.05 to 0.07	66 216	43 800	66.15	27.60	54.13
			0.07 to 0.10	66 369	44 480	67.02	27.13	55.64
	VI	$\frac{7}{16}$ to $\frac{1}{2}$	0.05 to 0.07	65 580	42 540	64.87	27.92	54.30
			0.07 to 0.10	65 856	42 846	65.06	27.42	53.15

Analyzing this record, it will be found that the higher phosphorus gives a higher elastic ratio in all six groups. The difference, however, is only a fraction of 1% in each case, so that it is of little practical importance. The higher phosphorus gives a better elongation in all four groups of the softer steel, and a less elongation in the harder steel. A general conclusion to this effect would not be justified, but it can certainly be stated that a moderate increase in phosphorus does not materially reduce the elongation of soft steel. The higher phosphorus gives a better reduction of an area in four groups, and a worse reduction in two groups. Here, again, it may be confidently concluded that a moderate increase in phosphorus does not seriously decrease the reduction of area.

It is the difference between static and shock ductility which makes phosphoric steel so dangerous. In the ordinary testing machine there is no important difference between a pure steel containing less than .04% of phosphorus, and a common steel with .08%, so that the average engineer concludes that the metals are the same. Not only constructive engineers, but men calling themselves metallurgists have staked and have lost their reputations in promoting new processes designed to make good finished material out of steel containing high phosphorus. Many a time the metallurgical world has been stirred by some new discovery, whereby such metal was induced to show a high ductility in the testing machine, and each time the new process has passed away "unwept, unhonored and unsung," as it was rediscovered and rediscovered that static and shock ductility were totally different properties, and that the high phosphorus metal gave lamentable failures as soon as it went beyond the watchful care of its parents and its nurses. It is true that numerous cases can be cited of rails, plates, etc., containing from .10 to .35% of phosphorus, which have withstood a long lifetime of wear and adversity, but in the general use of such metal there has been such a large percentage of mysterious breakages, that it seems quite well proven that the phosphorus and the mystery are the same.

Much information on the effect of phosphorus may be gathered from a study of high steels. A very severe trial is put upon a cold chisel or similar tool in the resisting of the continued shock on the sharpened edge, and it is undeniable that each increment of phosphorus has its effect in rendering such a tool brittle. It is true that in this case the steel is quenched, and also that it contains a considerable proportion of carbon, but there is no evidence to show that the effect of phosphorus is different when the carbon is high, even though it be true that it is more marked. Neither is there any reason to suppose that the quenching changes its nature for experiments with high phosphorus steel of low carbon indicate that sudden cooling would rather counteract the influence of phosphorus than enhance it, since it tends to prevent the formation of coarse crystals. It would seem, therefore, that the regularly increasing banefulness of phosphorus as the carbon is raised does not portray any change in nature, but that, although the effect of the metalloid in lower steels is obscured, its character is the same. No line can be drawn that can be called the limit of safety, since no

practical test has ever been devised which completely represents the effect of incessant tremor. For common structural material the critical content has been placed by general consent at .10%, but this is altogether too high for railroad bridge work. All that can be said is, that safety increases as phosphorus decreases, and the engineer may calculate just how much he is willing to pay for greater protection from accident.

The Physical Properties.

One of the fundamental difficulties in writing specifications is to decide the nature of the test piece to be required, inasmuch as the strength and ductility will be very different in plates of different thickness, and the properties of these will differ from the properties of angles or rounds which may be rolled from the same steel. From one point of view, each piece of metal throughout a bridge should be of exactly the same strength per unit of section, without regard to its thickness, but in taking this as a basis a serious trouble is encountered. Suppose, for instance, that a metal is required running between 56 000 and 64 000 lbs. per square inch, and a charge is made which in ⅝-in. plate gives 57 000 lbs. If this steel be rolled into ⅞-in. angles or into 2-in. rounds, it is quite possible that these will run below the allowable minimum. On the other hand, if the steel gives 62 000 lbs. in a preliminary test, the larger sections will give proper results, while ¼-in. plate will be too high in ultimate strength.

Where a structure is to be made of large quantities of very large or very small sections, it is well to specify that the test shall be made on the special thickness needed; but in ordinary cases, it seems absurd to the practical mind that a heat of steel can be perfectly suitable for one size and unsuitable for another. It would be very expensive for manufacturers to fill contracts were it not that inspectors recognize the situation and make tests from the usual sizes, with a full knowledge that thicker and thinner members will give different results. Provisions to cover this point should be incorporated in contracts, and a certain definite allowance be made, so that manufacturers would be obliged to put sufficient work on large members to render them of proper structure, and would at the same time be prevented from finishing thin pieces at too low a temperature. There is often a confusion of terms in considering the effect of work, as represented by a

large percentage of reduction from the ingot, and the effect of finishing at a low temperature. This is found most often in the case of plates, for it has been quite a general practice to roll these direct from the ingot in one heat. In order that a piece shall be finished hot enough under this practice, there has been a standing temptation to use a thin ingot; but, on the other hand, it has been almost universally shown that the best results are obtained when a large amount of work is put upon it in the rolling.

The truth of this last statement was disputed by Mr. Riley,* but it can be shown that his conclusions are not in accord with his premises, and that the best plates were those that received the most work. It will be evident, however, that when a heavy ingot is rolled down to a thin plate in one operation, there will be an enormous strain on the machinery, and probably a cold-finished piece. The effect of this cold finish is very irregular, for the edges and ends are most seriously affected, and the plate is in a bad physical condition. To avoid, on the one hand, the objectionable cold finish, and to give, on the other, the advantage of sufficient work, the practice has been gaining ground of rolling a large ingot into a slab, which is proportioned to the plate to be made. By this method all thicknesses may be finished at about the same temperature, without respect to the total amount of work put upon the ingot.

It is a well-known fact that a mass of steel is never absolutely homogeneous owing to certain liquation phenomena known as segregation, and, as it is reasonable to suppose that this action will take place to a greater extent in a large mass of metal than in a small one, it is usually assumed that plates which have been rolled from ingots of large size will show greater variations than those from more usual sections. Paradoxical as it may appear, this is not always true, for in the preliminary "roughing down," or slabbing, of the ingot, the top, which is the most segregated portion, is cut off as scrap. The upper third of the ingot will even then show some segregation in the interior, but Table No. 5 will show that it is of little practical importance.

* See the *Journal* of the Iron and Steel Institute, Vol. I, 1887.

TABLE No. 5.

COMPOSITION OF METAL TAKEN AT DIFFERENT DEPTHS IN OPEN-HEARTH SLABS, ROLLED FROM 32 × 38-IN. INGOTS, MADE BY THE PENNSYLVANIA STEEL COMPANY.

Note: Carbon was determined by color, and is therefore inaccurate.

Number of heat.	Part of ingot.	Size of slab, in inches.	Depth at which drillings were taken, in inches.	Composition. Per Cent.			
				C.	P.	S.	Mn.
8 188.....	Top slab.	5 × 26	1	.15	.027	.017	.52
			2	.21	.041	.026	.57
			3	.14	.026	.017	.52
8 192.....	Top slab.	7 × 18	1	16	.019	.021	.56
			2	.16	.018	.019	.56
			3	.19	.018	.021	.60
10 037.....	Top slab.	6½ × 26	1	.21	.058	.037	.77
			2	.20	.059	.037	.77
			2½	.20	.053	.040	.81
			3½	.22	.060	.040	.85
			4	.23	.061	.048	.83
8 201.....	Top slab.	6 × 18	½	.13	.033	.029	.49
			1½	.13	.034	.036	.49
			2½	.12	.034	.032	.49
			3½	.11	.024	.022	.47
	Slab one-third way down the same ingot.	6 × 18	½	.13	.037	.033	.49
			1½	.13	.038	.038	.48
			2½	.14	.046	.047	.49
			3½	.15	.050	.050	.49
8 202.....	Top slab.	6 × 18	½	.11	.030	.022	.42
			1½	.11	.033	.022	.43
			2½	.11	.031	.022	.42
			3½	.11	.031	.022	.43
	Slab one-third way down the same ingot.	6 × 18	½	.12	.039	.023	.43
			1½	.13	.038	.026	.42
			2½	.15	.040	.026	.42
			3½	.15	.048	.048	.42

These results were obtained by drilling slabs rolled from acid open-hearth ingots with a cross-section of 32 × 38 ins., and weighing about 20 000 lbs., such ingots being in common use at Steelton for making slabs for boiler plate and bridge material. The slabs, which were from 5 to 7 ins. thick, were drilled in the middle, and samples of the metal were taken at different depths until the center had been passed. The table shows quite a difference in some cases between the center and the outside of a slab, but it will be con-

sidered that the subsequent rolling into a plate will tend to equalize the composition, and that in any event the center constitutes but a small portion of the total section. In addition to this fear of segregation in large ingots, there is a shadowy feeling in the minds of some engineers as to the homogeneity of a very large heat of steel. In order to satisfy this very reasonable doubt, Table No. 6 gives the records obtained from 20 tests taken at random from the pile of rivet rods from a representative low-phosphorus rivet heat, without any knowledge as to what part of the heat or what part of the ingots the tests came from.

TABLE No. 6.

TESTS ON RIVET ROUNDS TAKEN FROM DIFFERENT PARTS OF THE SAME ACID OPEN-HEARTH HEAT.

Heat No. 10 168. Pennsylvania Steel Company. Weight of Heat, 110 000 lbs. Composition, Per Cent. C. = .12; P. = .013; S. = .024; Mn. = .29; Cu. = .27.

Diameter of bar.	Ultimate strength. Pounds per square inch.		Elastic limit. Pounds per square inch.		Elongation in. 8 ins. Per cent.		Reduction of area. Per cent.	
	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
¾ in....	55 480	49 460	37 600	29 870	32.50	28.75	67.45	65.30
" ..	55 480	49 940	36 670	30 350	32.50	31.25	68.22	65.30
" ..	55 430	49 460	38 400	30 110	33.25	31.75	68.40	67.70
" ..	55 400	49 700	37 250	31 300	30.00	35.00	64.67	69.22
" ..	55 160	49 700	37 950	32 730	30.00	32.50	64.97	69.22
" ..	54 770	50 720	37 600	31 760	32.50	30.00	69.68	64.62
" ..	54 750	50 420	38 400	32 740	33.75	33.75	63.15	61.12
" ..	54 690	50 010	39 120	32 470	32.75	32.50	67.35	67.96
" ..	54 520	50 880	38 640	32 220	33.00	31.25	67.17	67 25
" ..	54 220	49 770	38 900	32 230	33.75	33.75	66.57	69.47
Av'ge.	54 990	50 006	38 054	31 578	32.40	32.05	66.76	66.72
⅞ in....	55 000	50 230	37 710	31 950	31.75	33.75	66.31	70.77
" ..	54 780	49 170	37 100	30 310	33.75	36.00	62.83	68.77
" ..	54 700	50 880	36 750	31 620	32.50	34.00	60.11	66.70
" ..	54 180	48 820	37 450	30 840	31.75	35.00	62.30	68.77
" ..	54 170	48 290	36 580	30 840	31.25	34.00	67.83	68.77
" ..	53 880	48 930	36 320	30 730	31.00	36.00	60.20	68.43
" ..	53 770	50 520	35 610	31 670	32.50	34.00	60.02	65.08
" ..	53 770	49 060	35 960	31 120	32.75	35.50	65.73	69.76
" ..	52 860	50 160	35 700	31 920	33.25	35.50	61.39	69.57
" ..	52 600	50 640	35 360	32 400	33.00	35.00	68.49	68.62
Av'ge.	53 970	49 670	36 450	31 340	32.35	34.87	63.52	68.52

The data on the natural bars are arranged in the order of tensile strength, while in parallel columns are given the results obtained by annealing the same bar. Although all the pieces of one heat were heated at the same time and with the utmost care to have all conditions uniform, it will be seen that the variations in the strength of the annealed bar are entirely independent of the variations in the strength of the natural bar. This would indicate that the differences are due to the irregularities in rolling and to determinative errors rather than to any inherent variations in the character of the metal. In further proof of this, drillings were taken from the three annealed bars of heat No. 10 168 which showed the highest tensile strength and from the three which were weakest. The results of analysis are given in Table No. 7.

TABLE No. 7.

COMPOSITION OF RIVET RODS IN TABLE No. 6, WHICH SHOW THE GREATEST DIFFERENCES IN THE TENSILE STRENGTH OF THE ANNEALED BARS.

NATURE OF PIECE.	Ultimate strength. Pounds per square inch.		Composition. Per cent.			
	Natural.	Annealed.	C.	P.	S.	Mn.
Preliminary test....	52 280	.....	.12	.013	.024	.29
Average of strongest three bars.....	53 690	50 680	.12	.013	.019	.30
Average of weakest three bars	54 077	48 680	.12	.013	.024	.30

These data on rivet rods may seem rather foreign to the question of the determination of the physical properties, but in reality they are of vital importance; for it is here shown that the most homogeneous steel shows variations in different bars which are not due at all to any fault of the steel or to differences of section, but simply to the accumulation of petty errors, and that the variations so produced may amount to 2 000 lbs. or more per square inch in ultimate strength. This fact is most surely of interest in deciding the limits of variation which are to be allowed in the manufacture of structural material.

In addition to these effects of determinative errors there are differences which are due simply to the shape of the piece. By this is not meant the variations that will be found in pieces cut from shapes of radically different section, but those which may be detected by a care-

TABLE No. 8.

Comparative Physical Properties of ¾-in. Rounds and 2 x ⅜-in. Flats Rolled from the Same Billet.

Limits of ultimate strength. Pounds per square inch.	Kind of steel.	Number of heats in average.	Ultimate strength. Pounds per square inch.		Elastic limit. Pounds per square inch.		Elongation in 8 ins. Per cent.		Reduction of area. Per cent.		Elastic ratio.	
			Round.	Flat.	Round.	Flat.	Round.	Flat.	Round.	Flat.	Round.	Flat.
Natural Bars.												
56 000 to 60 000	Bessemer	11	58 869	58 458	42 318	41 698	27.75	31.45	58.83	56.13	71.88	71.33
	Open hearth	4	53 568	58 130	40 300	40 400	29.69	30.13	60.78	61.75	68.81	69.51
60 000 to 64 000	Bessemer	6	62 087	60 825	45 323	43 135	27.04	30.42	55.31	56.20	73.00	70.92
	Open hearth	7	62 187	62 089	42 606	42 441	28.04	30.14	62.16	60.86	68.51	68.36
64 000 to 68 000	Bessemer	9	66 241	64 621	47 568	45 194	26.08	28.42	50.07	47.80	71.81	69.94
	Open hearth											
68 000 to 72 000	Bessemer	3	70 457	69 773	50 263	49 060	24.75	26.67	48.30	48.40	71.34	70.31
	Open hearth	2	70 530	69 420	49 000	45 090	26.88	25.63	61.10	59.30	69.47	64.96
72 000 to 80 000	Bessemer	11	77 440	76 900	53 760	52 240	24.06	23.44	42.35	40.15	69.42	67.93
	Open hearth	12	76 616	75 865	51 108	49 691	24.52	24.69	53.73	54.40	66.71	65.50
Same Bars Annealed.												
56 000 to 60 000	Bessemer	11	55 703	54 194	37 828	35 603	29.14	30.05	66.55	63.13	67.91	65.70
	Open hearth	4	54 098	51 418	31 823	30 393	28.75	31.06	62.65	60.50	58.82	59.11
60 000 to 64 000	Bessemer	6	59 372	56 192	40 570	37 542	30.13	30.63	65.50	63.33	68.33	66.81
	Open hearth	7	58 364	55 021	35 120	31 576	28.61	30.36	63.47	60.00	60.17	57.39
64 000 to 68 000	Bessemer	9	61 694	58 838	42 228	38 476	28.25	28.36	62.91	59.01	68.45	65.39
	Open hearth											
68 000 to 72 000	Bessemer	3	65 903	64 160	44 660	43 770	26.08	28.58	63.23	59.50	67.76	68.22
	Open hearth	2	65 500	60 850	37 685	34 000	23.38	26.50	55.30	52.10	57.53	55.87
72 000 to 80 000	Bessemer	11	71 548	68 780	47 643	43 568	25.81	26.38	57.53	51.00	66.59	63.34
	Open hearth	12	69 402	67 618	40 505	39 403	23.04	26.31	56.54	51.36	58.36	58.27

ful comparison of pieces which have been worked under very similar conditions. The following investigation examines at some length the physical properties of round and flat test bars. A billet was cut from a large number of Bessemer and open-hearth heats, and one-half of this billet was rolled into a ¾-in. round, and the other half into a 2 x ⅜-in. bar. The results are shown in Table No. 8.

All the lessons of this table are not written on its face, but by examination we may discover the following facts:

First.—Taking into consideration both natural and annealed bars, there are 18 comparisons between rounds and flats. The ultimate strength is less in the flat in every case. The elastic limit falls in 17 cases, and the gain in the exception is slight. The elongation is raised in 16 cases, while in the two exceptions the loss is small. The reduction of area is lowered in 14 cases, and raised in four. The elastic ratio is lowered in 15 cases, while in the exceptions the increase is small.

Second.—Comparing the loss of strength in passing from round to flat, there are nine possible comparisons between the loss in the natural bar and the loss in the annealed piece. The ultimate strength falls more in every case in the annealed than it does in the natural bar. The elastic limit falls in six cases, and rises to a much less extent in three. The elongation rises in five cases, and falls in four. The reduction of area falls in all cases. The elastic ratio falls in five cases, and rises in four.

It will be found that the exceptions and irregularities are not confined to any one kind of steel, so that it would seem proper to average the losses and gains in order to estimate the errors due to the small number of heats in some of the groups. The results of such condensation are given in Table No. 9, which shows the true average of all the heats and not the average of the groups.

It is shown that the loss of ultimate strength from the round to the flat is very much greater in the annealed than in the natural bars, and that the elastic limit more than keeps pace with it, as shown by the elastic ratio. The difference can hardly be due to the effect of varying work, for the round was reduced to 2.6% of the area of the billet, and the flat to 4.7%, the reduction in both cases being so heavy that the results should be uniform as far as this factor is concerned. The effect of the finishing temperature may be ignored in the case of the annealed pieces, and yet there is a difference of 2 448 lbs. per square

TABLE No. 9.

COMPARATIVE PHYSICAL PROPERTIES OF ROUND AND FLAT BARS IN THE NATURAL AND ANNEALED STATES; BEING A SUMMARY OF THE BARS GIVEN IN TABLE No. 8.

Average of all heats given in Table No. 8.	Condition of bar.	Shape of Bar.		Gain = + Loss = −
		Round.	Flat.	In Flat.
Ultimate strength; pounds per square inch.....	Natural.	56 679	65 911	− 768
	Annealed.	62 015	59 567	− 2 448
Elastic limit; pounds per square inch.....	Natural.	46 588	45 268	− 1 320
	Annealed.	39 633	37 106	2 527
Elastic ratio; pounds per square inch.....	Natural.	69.87	68.68	− 1.19
	Annealed.	63.91	62.29	− 1.62
Elongation in 8 ins.; per cent.....	Natural.	26.48	28.22	+ 1.74
	Annealed.	27.16	28.73	+ 1.57
Reduction in area; per cent.....	Natural.	54.98	54.05	− 0.93
	Annealed.	61.98	58.12	− 3.86

inch in ultimate strength between the flat and round. The natural bars show less difference, which would indicate that the effect of the finishing temperature has raised the strength of the flat more than the round. This is contrary to the condition just noted that the reduction in rolling was less in the case of the flat, but it is in accord with the evident fact that a thin bar would cool faster than a round bar of somewhat less sectional area. The effect of the finishing temperature therefore was to raise the tensile strength of the flat more than it did the round, but not enough to overcome the difference in physical properties caused by the shape of the bars. The reduction of area is less in the case of the flat, and the difference is more marked in the annealed than in the natural bars. The elongation is higher in both kinds of flats that in the corresponding rounds, but the difference is greater in the natural bars. This appears at first sight to be an exception, but on further consideration it will be seen that a decrease in gain is equivalent to a loss, and this brings it in accord with the decrease in ductility as shown by the lessened reduction of area. The net result may be summarized as follows:

First.—Flat bars differ from rounds in having less tensile strength, lower elastic limit, lower elastic ratio, greater elongation and a slightly lower reduction of area.

Second.—This difference is caused, not by reason of a different finishing temperature, but in spite of it.

These results show that a certain appreciable variation may arise from a mere difference in the section of the test piece, even where the conditions of rolling or of heat treatment are as constant as can be obtained by more than ordinary care. It will be evident that much greater changes can be produced in the practical manufacture of large sections of varying thicknesses. This will be shown in Table No. 10, which compares the tests on the finished angles from acid open-hearth heats with the results obtained from bars rolled from a 6-in. square test ingot. This preliminary test bar will not give a good elongation owing to insufficient work, but it is found to give closely comparable results in ultimate strength. The relative variations from this, as a standard, will therefore portray the influence of the thickness of the bar.

TABLE No. 10.

COMPARATIVE ULTIMATE STRENGTH OF BARS ROLLED FROM A TEST INGOT, 6 INS. SQUARE (PRELIMINARY TEST), AND TEST PIECES CUT FROM ANGLES OF DIFFERENT THICKNESSES ROLLED FROM THE SAME HEATS. MADE BY THE PENNSYLVANIA STEEL COMPANY.

Thickness of Angle in Inches.	Number of heats.	Ultimate Strength. Pounds per Square Inch.			Elastic Limit. Pounds per Square Inch.			Elastic Ratio.	
		Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.
$\frac{1}{2}$ and $\frac{3}{8}$.....	39	60 200	60 190	10	42 270	41 300	970	70.23	68.62
$\frac{5}{8}$ and $\frac{1}{2}$.....	46	61 360	60 660	700	43 070	40 170	2 900	70.19	66 22
$\frac{3}{4}$ and $\frac{5}{8}$.....	37	62 930	61 520	1 410	42 990	39 710	3 280	68.31	64.55

It is shown that for an increase of $\frac{1}{8}$ in. in thickness there is a diminution in strength of 700 lbs. per square inch. When a large lot of angles or plates are to be rolled of a special thickness, this matter of ultimate strength may be regulated by making a softer or harder steel; but in making a small and miscellaneous lot of sizes and thicknesses, it is evidently impossible to make different heats for each thickness.

TABLE No. 11.

COMPARATIVE PHYSICAL PROPERTIES OF VARIOUS STEELS MADE BY THE PENNSYLVANIA STEEL COMPANY WHEN ROLLED INTO ANGLES OF DIFFERENT THICKNESS.

No. of group.	Kind of steel.	Limits of phosphorus in group. Per cent.	Limits of ultimate strength in group. Per cent.	Thickness of angle, in inches.	Number of heats in average.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch	Average elastic ratio.	Average elongation in 8 ins. Per cent.	Average reduction of area. Per cent.
I.....	Basic open hearth...	below .04	47 000 to 55 000	$\frac{5}{16}$ to $\frac{1}{2}$	29	52 605	35 910	68.26	32.21	63.85
				$\frac{15}{16}$ to $\frac{7}{8}$	16	52 061	33 405	64 17	33.19	64.20
II.....	Basic open hearth...	below .04	55 000 to 63 000	$\frac{5}{16}$ to $\frac{1}{2}$	22	58 784	39 340	66.92	30.26	59.38
				$\frac{15}{16}$ to $\frac{7}{8}$	6	58 792	37 388	63.60	30.58	56.72
III.....	Acid open hearth...	.05 to .07	56 000 to 64 000	$\frac{5}{16}$ to $\frac{7}{16}$	22	60 443	40 929	67 72	28.66	58 52
				$\frac{1}{2}$ to $\frac{9}{16}$	23	61 173	40 164	65.66	28 72	55.73
				$\frac{5}{8}$ to $\frac{11}{16}$	20	61 318	39 548	64.50	28.31	52 92
				$\frac{3}{4}$ to $\frac{7}{8}$	31	60 609	38 559	63.63	28.62	50.09
IV.....	Acid open hearth....	.07 to .10	56 000 to 64 000	$\frac{5}{16}$ to $\frac{7}{16}$	50	60 064	41 143	68.50	28.82	58.35
				$\frac{1}{2}$ to $\frac{9}{16}$	50	60 583	40 170	66.30	29.05	56.30
				$\frac{5}{8}$ to $\frac{11}{16}$	50	61 049	39 656	64.96	28.98	54.81
				$\frac{3}{4}$ to $\frac{7}{8}$	50	59 763	38 338	64.15	29.60	55.33
				$\frac{15}{16}$ to 1	50	61 129	37 969	62.11	28.85	50.80
V.....	Acid Bessemer.....	.07 to .10	56 000 to 64 000	$\frac{5}{16}$ to $\frac{7}{16}$	150	60 659	43 417	71 58	28.07	56.60
				$\frac{1}{2}$ to $\frac{9}{16}$	200	59 882	42 518	71.00	28.63	56.81
				$\frac{5}{8}$ to $\frac{11}{16}$	200	59 415	41 063	69.11	28.95	55.60
				$\frac{3}{4}$ to 1	200	58 267	38 867	66.70	28.37	51.63
VI.....	Acid open hearth....	.05 to .07	64 000 to 72 000	$\frac{5}{16}$ to $\frac{7}{16}$	12	66 216	43 800	66.15	27.60	54.13
				$\frac{1}{2}$ to $\frac{9}{16}$	21	65 580	42 540	64.87	27.92	54.30
VII.....	Acid open hearth....	.07 to .10	64 000 to 72 000	$\frac{5}{16}$ to $\frac{7}{16}$	24	66 366	44 480	67.02	27.13	55.64
				$\frac{1}{2}$ to $\frac{9}{16}$	35	65 856	42 846	65.06	27.42	53.15
VIII.....	Acid Bessemer.....	.07 to .10	64 000 to 72 000	$\frac{5}{16}$ to $\frac{7}{16}$	50	66 359	46 512	70.09	26.36	50 15
				$\frac{1}{2}$ to $\frac{9}{16}$	23	65 940	45 280	68.66	27.30	51.52

Fortunately, the differences in ultimate strength are usually not very marked, although they do often give rise to more or less trouble. The variations in elastic limit and reduction of area are not so trivial, as may be seen in Table No. 11, which gives the average results from angle bars of several different kinds of steel. No comparison of the ultimate strength is possible, for each bar is from a different heat; but as all the steels in any group were made in the same department, and all were rolled in the same mill and tested in the same laboratory, the other factors may be regarded as fairly comparable.

It will be seen that there is a reasonably regular law that the elastic ratio and reduction of area decrease with increasing thickness, while the elongation remains the same. In the same way that the physical properties vary in angles of different thicknesses, so will they be different in angles and plates. This will be illustrated by Table No. 12, which compares the results obtained from the steel made by The Pennsylvania Steel Company when rolled into angles and plates. In both cases there is no selection of tests, but all pieces, good, bad and indifferent, are taken as they appear upon the records.

TABLE No. 12.

COMPARATIVE PHYSICAL PROPERTIES OF ANGLES AND SHEARED PLATES, BOTH BEING MADE FROM STEEL MADE BY THE PENNSYLVANIA STEEL COMPANY.

Thickness of bar.	Kind of piece.	Number of heats in average.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
BASIC OPEN-HEARTH SOFT STEEL.							
$\frac{5}{16}$ to $\frac{3}{8}$	Angles	31	55 718	38 105	68.39	30.92	62.3
	Plates	156	56 430	40 984	72.63	27.86	57.3
$\frac{7}{16}$ to $\frac{1}{2}$	Angles	17	55 307	35 919	64.94	31.78	60.9
	Plates	20	55 335	36 290	65.58	29.91	57.2
BASIC OPEN-HEARTH MEDIUM STEEL.							
$\frac{5}{16}$ to $\frac{3}{8}$	Angles	17	58 383	39 657	67.93	30.47	60.4
	Plates	107	59 630	43 356	72.71	27.11	57.7
ACID OPEN-HEARTH SOFT STEEL.							
$\frac{3}{8}$	Angles	42	59 843	40 721	68.05	28.92	58.4
	Plates	12	61 961	42 567	68.70	25.48	51.0
$\frac{7}{16}$ to $\frac{1}{2}$	Angles	50	60 583	40 170	66.30	29.05	56.3
	Plates	53	60 711	39 690	65.38	24.56	51.4

This shows that a less percentage of elongation can be expected from a plate than from an angle of the same thickness. No data are given of plates thicker than ½ in., but it is quite clear that, when all other things are equal, an increase in thickness is accompanied by a reduction in the ductility. The heads of two widely known plate mills have given the author as their estimate that, taking ½ in. as a basis, there will be the following changes in the physical properties for every increase of ¼ in. in thickness:

First.—A decrease in ultimate strength of 1 000 lbs. per square inch.

Second.—A decrease in elongation of 1%, when measured in an 8-in. parallel section.

Third.—A decrease in reduction of area of 2 per cent.

It should also be mentioned that in the case of plates less than $\frac{5}{16}$ in. in thickness, the test will give a high ultimate strength and a low ductility. In order to do away with the variations in the physical properties of different shapes, it has been proposed that the steel be accepted or rejected on the result of what is known as the "preliminary test," *i. e.*, a bar rolled from a small test ingot. No less an authority than Mr. A. E. Hunt has advocated this method,* claiming that it is "convenient," and that it is the "fashion." Consequently, Mr. Hunt would accept the steel on the "preliminary test, provided that the finished material comes within 4% of the standard thus obtained."

It seems to the author that this provision is a *reductio ad absurdum*, for if the finished material is to be tested at all, what has the "preliminary" to do with the question? It is true that it is the "fashion" to make such a test, and nowhere more than at Steelton, but this is done to prevent mistakes. We find that the ultimate strength of the test represents the ultimate of the finished bars, and without regard to any results on elongation or other qualities, we use or lay aside the charge. We are perfectly willing that the inspectors should see all the results, but we claim that it has nothing to do with the acceptance or rejection of the material. We prefer to roll a flat bar rather than a round, since this form allows drifting or bending tests, although it is recognized that the elongation and reduction of area will be different in flats and rounds. In other words, this test is our own work, and the business of the inspector is to test the material that he buys as

* See the *Journal* of the Iron and Steel Institute, Vol. II, 1890.

fully and carefully as he may wish, without regard to whether a small test ingot has or has not fulfilled certain requirements, or whether it has been made at all. Convenience has no place in this matter, save where it is a mutual arrangement to the satisfaction of all concerned, whereby unnecessary delay and friction may be avoided. Our experience in comparing results from the preliminary test with those from the finished material differs radically from that recorded by Mr. Hunt for the elongation and reduction of area are much inferior in the small test. We fully understand that this is on account of the method of working, but we know also that any change would result in less uniformity in the matter of ultimate strength, which is of great importance to us, and we claim the right to do as we wish with this test, granting to the engineer the right to do as he wishes with the finished material.

Another method by which it is hoped to overcome the effect of varying shape is to make the length a function of the sectional area. The formula which is advocated by the Committee of the American Society of Mechanical Engineers is—

$$L = 12\sqrt{F}$$

where L = the length in inches,

and F = the sectional area in square inches.

Thus in the case of rounds, for example, the length of the test piece will increase with every increase in diameter, which is the same thing as saying that for an equal length of piece an increased elongation will be demanded. In view of this advocacy of varying length, the information which has been published on the influence of changes in length upon the percentage of elongation is not as accurate as might be wished. The results of M. Barba* have long been accepted as authoritative, and they are given in Table No. 13.

Not satisfied with these experiments, the writer conducted the following investigation: Twenty rods ¾ in. in diameter were selected from one heat of acid open-hearth steel. From each rod seven bars were cut, one of which was tested in a length of 2 ins., and one each in 4, 6, 8, 10, 12 and 14 ins. The results are given in Table No. 14.

Fig. 1 shows these data and those from Barba, when plotted in curves.

* See the *Mémoires* of the Society of Civil Engineers of France, Vol. I, 1880.

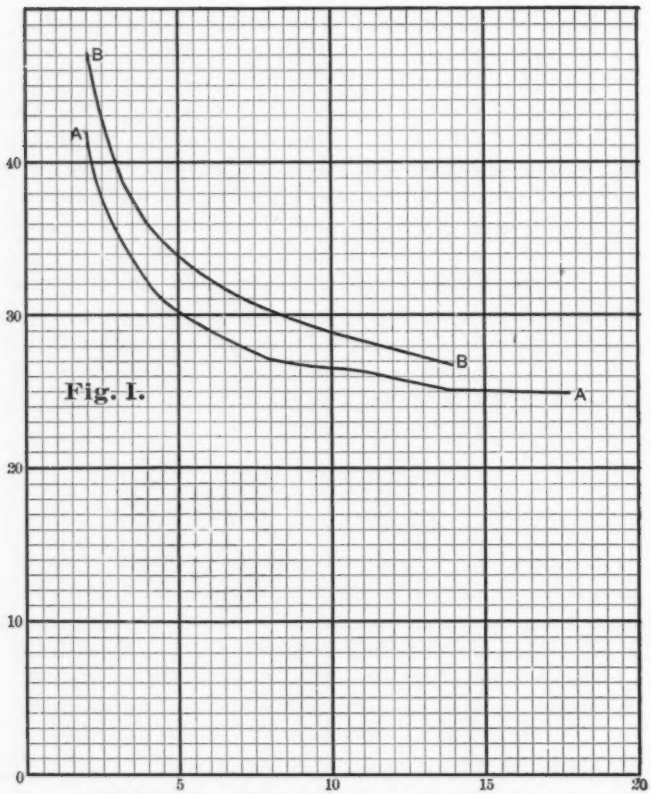

Fig. I.

EFFECT OF A CHANGE IN THE LENGTH OF THE TEST PIECE UPON THE ELONGATION.

Curve A A from Barba (See Table 13)
Curve B B from P.S.Co. (See Table 14)
Abscissas = Length, in inches.
Ordinates = Elongation, per cent.

TABLE No. 13.

INFLUENCE UPON THE ELONGATION OF A CHANGE IN THE LENGTH OF THE TEST PIECE, THE DIAMETER REMAINING CONSTANT.

Number of bar.	Dimensions in Inches.		Ratio of length to diameter.	Elongation. Per cent.
	Length.	Diameter.		
1	1.97	0.677	2.91	42.0
2	3.94	0.677	5.81	32.0
3	5.91	0.677	8.72	29.3
4	7.87	0.677	11.60	27.2
5	9.84	0 677	14.50	26.6
6	11.81	0.677	17.40	26.0
7	13.78	0.677	20.30	25.1
8	15.75	0.677	23.30	25.0
9	17.72	0.677	26.20	24.9

This law of decrease in elongation with increase in length holds good in extreme lengths, as will be shown by Table No. 15, which gives the result of averaging a large number of eye-bar tests, for which the author is indebted to the Union Bridge Company.

TABLE No. 14.

INFLUENCE UPON THE PHYSICAL PROPERTIES OF A CHANGE IN THE LENGTH OF THE TEST PIECE.

Pennsylvania Steel Co. Acid Open-Hearth Steel. Each figure is the average of 20 tests.

Length of test piece in inches.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of Area. Per cent.
2	60 685	42 548	70.11	47.43	66.7
4	60 343	43 134	71.48	36.11	66.9
6	60 099	42 951	71.47	32.17	67.1
8	60 123	43 159	71.78	30.16	66.8
10	60 068	43 161	71.85	28.96	67.3
12	60 059	43 024	71.64	27.87	67.2
14	60 066	43 234	71.98	26.76	67.1

In addition to the changes that may be produced by varying the length of the test piece, the width of the specimen has a bearing upon the result. For the purposes of experiment five strips of different widths were cut side by side from specimen plates of 30 different heats. The results are given in Table No. 16, and the conclusions therefrom may be summarized as follows :

TABLE No. 15.

PHYSICAL PROPERTIES OF EYE-BARS, CLASSIFIED ACCORDING TO LENGTH. MADE BY THE UNION BRIDGE COMPANY.

Number of heats represented.	Limits of length in group. In feet.	Average length of group. In feet.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Elongation in full length. Per cent.	Elongation in the 12 ins., including the fracture. Per cent.	Reduction of area. Per cent.
41...	10 to 12	11.8	59 880	35 240	18.07	34.68	46.95
102...	13 to 16	14.8	59 830	35 460	18.05	35.75	48.43
215...	17 to 20	18.6	59 770	35 540	16.58	35.04	48.37
245...	21 to 25	22.9	60 380	35 460	15.75	35.37	47.72
145...	26 to 30	28.0	59 520	35 310	15.37	36.36	49.25
82...	31 to 35	33.1	59 900	35 470	14.17	34.73	49.85
830...	All lengths.	.....	59 930	35 440	.....	35.41	48.42

First.—Variations in the width of the test piece have very little effect upon the ultimate strength.

Second.—They probably have little influence upon the elastic limit. The narrow pieces show a decided increase in the elastic ratio, but this needs further corroboration.

Third.—They have little effect upon the reduction of area, but a slight deterioration is indicated with increase of width.

Fourth.—The elongation improves as the width increases.

This fact is well understood by manufacturers, and for this reason there is a tendency toward the use of very strong machines, for in this manner a thick plate may be tested in a wide bar, and thus give a better result. This cannot be called unfair, but the results are misleading when compared with those of other works. The whole proceeding can be stopped by limiting the sectional area of the test piece to an ordinary figure. Still another point which influences the recorded physical properties is the pulling speed of the machine. This is illustrated in Table No. 17, where it is shown that a decrease in speed is accompanied by a decrease in ultimate strength, elastic limit, elastic ratio, and elongation. In the case of the slowest speed, there is a marked exception to this rule, but this point is not of great practical importance since it requires nearly an hour to break a single bar of ductile steel at this speed.

TABLE No. 16.

EFFECT OF CHANGES IN THE WIDTH OF THE TEST PIECE UPON THE PHYSICAL PROPERTIES. AVERAGE OF STRIPS FROM SHEARED PLATES FROM 30 HEATS OF THE PENNSYLVANIA STEEL COMPANY STEEL.

Width of test piece in inches.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of Area. Per cent.
½	70 578	46 284	65.58	23.87	59.43
¾	69 872	44 022	63.00	25.21	58.46
1	69 967	43 579	62 29	26.25	58.29
1½	70 176	43 588	62.11	27.25	58.09
2	70 068	43 570	62.18	27.92	56.20

TABLE No. 17.

EFFECT OF VARIATIONS IN THE PULLING SPEED OF THE TESTING MACHINE UPON THE RECORDED RESULTS, MADE BY THE PENNSYLVANIA STEEL COMPANY.

Pulling speed. Inches per minute.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
4.50	61 075	45 708	74.84	30.32	64.96
3.00	60 672	44 410	73.20	30.18	64.83
0.67	59 523	42 904	72.08	29.45	65.82
0.38	59 387	41 763	70.32	29.33	65.69
0.07	59 027	39 647	67.17	31.93	66.48

The natural result of this investigation would be a tendency toward higher breaking speed. It is believed, however, that this may be carried too far, since with fast work it is more difficult to take accurate readings. The one important point to keep in mind is to have the details of testing as nearly uniform as possible among all manufacturers in order that each make of steel shall stand on its own merits.

CLASSES RECOMMENDED.

It is not the intention of this paper to state arbitrarily just what should or should not be given as the best tensile strength for every purpose, but it is the opinion of the author that a softer metal than is

often employed should be used for bridges, because although a slight sacrifice is made in the ultimate strength this is partly offset by the higher elastic ratio and a decided increase in toughness and resistance to shock, so that the calculations may be made on the same basis for the working load as with a harder metal. The fact that the elastic ratio rises as the ultimate strength decreases is not generally recognized, but will be shown in Table No. 18. This is constructed by comparing the groups of angles in Table No. 11, which are made by the same process, of the same thickness, and which contain the same percentage of phosphorus. It will be found that in every case the stronger steel gives a lower elastic ratio. The tendency in the first

TABLE No. 18.

RISE IN ELASTIC RATIO WITH DECREASE IN ULTIMATE STRENGTH. COMPARISON OF THE ANGLES IN TABLE No. 11, WHICH ARE MADE BY THE SAME PROCESS, OF THE SAME THICKNESS, AND WITH THE SAME CONTENT OF PHOSPHORUS.

Kind of steel.	Content of phosphorus. Per cent.	Thickness of angle in inches.	Harder Steels.			Softer Steels.			Rise in elastic ratio in softer steels. Per cent.
			Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Average elastic ratio. Per cent.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Average elastic ratio. Per cent.	
Basic open-hearth...	below 0.04	$\frac{5}{16}$ to $\frac{1}{2}$	58 784	39 340	66.92	52 605	35 910	68.26	1.34
		$\frac{5}{16}$ to $\frac{1}{2}$	58 792	37 388	63.60	52 061	33 405	64.17	0.57
Acid open-hearth....	0.05 to 0.07	$\frac{5}{16}$ to $\frac{1}{2}$	66 216	43 800	66.15	60 443	40 929	67.72	1.57
		$\frac{5}{16}$ to $\frac{1}{2}$	65 580	42 580	64.87	61 173	40 164	65.66	0.79
Acid open-hearth....	0.07 to 0.10	$\frac{5}{16}$ to $\frac{1}{2}$	66 369	44 480	67.02	60 064	41 143	68.50	1.48
		$\frac{5}{16}$ to $\frac{1}{2}$	65 856	42 846	65.06	60 583	40 170	66.30	1.24
Acid Bessemer	0.07 to 0.10	$\frac{5}{16}$ to $\frac{1}{2}$	66 359	46 512	70.09	60 659	43 417	71.58	1.49
		$\frac{5}{16}$ to $\frac{1}{2}$	65 940	45 280	68.66	53 882	42 518	71.00	2.34

epoch of steel structures was toward a hard alloy, but the later practice has been a continual progress toward toughness. There was a halt in this movement at a tensile strength of 60 000 lbs., not entirely on account of any magic virtue in that figure, but because the ordinary mild steels gave that result, and a much higher price was charged for a softer metal. Later improvements in manufacture and the introduction of the basic hearth have altered the economic situation. A steel with a tensile strength of 50 000 to 58 000 lbs. per square inch is a most

attractive material, possessing all the good characteristics of wrought iron with greater strength and toughness, and it seems probable that it will be extensively used in the future.

With this recommendation for the adoption of softer metal certain classes are proposed from which the engineer can choose. In some cases the option is given between acid and basic open-hearth steel, but it must not be forgotten that it costs more to make pure metal by the acid than by the basic process, so that the terms of the specification should be enforced after the contract is awarded out of justice to the other bidders who have based their calculations on the letter of the law. In steel above .08% phosphorus this difference in cost disappears, and there is no economy in the use of the basic hearth. The option is sometimes given between open-hearth and Bessemer metal, but it will be understood that whenever the former is specified, the latter is not admissible, although as a matter of course the manufacturer may supply open-hearth in place of Bessemer if for any reason he wishes to use the better and more expensive material. In the specifications for plates it will be noticed that a variation of 10 000 lbs. per square inch is allowed, and that concessions are made for thick and wide sections. All this may seem to some engineers to be a step backward, but in reality these provisions have been in force for many years.

The engineer who writes a new specification calling for a better elongation never knows that he receives exactly the same steel that has been made before. The plate rollers have been driven to expedients which are not dishonest, but which are dangerously near the line of deception. Thus, if it is required that a test must be cut from one plate out of every ten, the manufacturer will leave a coupon on every plate and will test strips which are cut from immediately next to them; after finding which plates fill the requirements, the coupons are cut from the others and the inspector is told that the pile is ready for him. If every plate is to be tested, then a coupon is left upon each corner and a contiguous strip is privately tested by the maker. After finding which corner gives the best results, the other coupons are cut off and the plate submitted to the inspector. This is not dishonest, for any one corner represents the plate just as much as any other corner, and it would manifestly be absurd to designate from which corner the test is to be taken. It is also quite certain that no one corner represents the center of the plate, for the edges are always finished colder than the

center, and it is just as certain that in a plate rolled direct from an ingot with only the usual amount of scrap, the corners in no way represent the part of the plate which corresponds to the segregated portion of the ingot. It is by care in the preliminary testing almost as much as in improvement in the quality of the material that advances have been made, and it is time that the fact be made known to engineers. The mill managers have been aided by the inspectors, for most of these men (to their credit be it said) are anxious to pass material which they know to be good. They allow the manufacturer to put part of a heat into thick plates and part into thin, and make the tests on the $\frac{3}{8}$ or $\frac{1}{2}$-in. gauges; they pass over the sheets that are 100 ins. wide and cut the coupons from plates that are less than 70 ins. wide. These concessions have been tacitly made in the past. The author has merely put them into print. On the other hand he has called for higher tests on plates under 42 ins. wide. This is because they can be made on a universal mill; and since better results can be had in this way, it is right to demand what there is a perfectly simple way of obtaining. It will be seen that no allowance is made for a variation in tensile strength for different shapes, while concessions are made for differences in thickness. This inconsistency arises from the fact that it is generally known beforehand whether a certain heat of steel is to be rolled into angles, or plates, or eye-bars, and it is seldom that it is necessary to put part of a heat into one shape and part into another. On the other hand it is almost always necessary to roll a charge into more than one thickness and more than one size of angles, plates, etc., and it is evidently an onerous restriction if proper allowance be not made for the normal variations due to different thicknesses.

Throughout the schedule the term "elastic limit" is used and not the new phrase "yield point." The author has no sympathy with that group of agitators who are trying to do what has so many times been proven to be impossible, to change a trade nomenclature without causing endless confusion. The absurd part of the whole business is that no attempt is made to create a new standard, but simply to change a name. If this were all, the effort would be of little import, but when it is proposed to appropriate the term "elastic limit" and make it denote a new point which is registered by certain autographic devices that are attached to some testing machines, then it is time to say that only harm can result from such misdirected efforts. Whether this

autographically registered point is or is not the true elastic limit is a matter in which we have a certain scientific interest, but let its parents christen it with a new name and not steal a term which is pre-empted by the copyright of general use.

General Provisions on Methods of Testing.

First.—Rivet rods and other rounds are to be tested in the form in which they leave the rolls, without machining.

> Note.—This is apparently opposed to the recommendations of the International Congress,* wherein it is proposed that round test pieces should be turned to one of four standard diameters, with shoulders and screw grips threaded at each end; but it is stated elsewhere in the Reports of the Committee that only pieces for scientific investigation are to be prepared in this manner.

Second.—Test pieces from angles, plates, shapes, etc., shall be rectangular in shape, with a cross-sectional area of about ½ sq. in., and shall be taken so that only two sides are machine-finished, the other two having the surface which was in contact with the rolls in the last pass.

> Note.—The report of the Committee above mentioned recommends this method of cutting tests, but specifies that there shall be shoulders at each end. This necessitates considerable extra machine work without any notable effect upon the result. The limitation of the area of the piece prevents the passing of inferior material by an unusual increase in width.

Third.—Should fracture occur outside of the middle third of the gauge length, the test is to be discarded as worthless if it falls below the standard.

> Note.—This provision is copied from the report of the Committee on Standard Tests of the American Society of Mechanical Engineers and is much to be commended. A deficient elongation when the piece breaks near the end is not the fault of the material, but a mere accident. On eye-bars, a failure in the eye should condemn the method of forming the head rather than the quality of the steel.

Fourth.—In case one test piece falls slightly below the requirements in any particular, the inspector shall allow the retesting of the lot or heat by taking four additional tests from the same lot or heat, and if

* See the Report of the Committee on Standard Tests of the American Society of Mechanical Engineers, Appendix V.

the average of the five shall show that the steel is well within the requirements, the material shall be accepted.

Fifth.—Drillings for chemical analysis may be taken either from the preliminary test piece or from the finished material, but if the sample be taken from the center of a sheared or universal mill plate, the maximum limit of both phosphorus and sulphur shall be raised 25%, viz., from 0.04 to 0.05%, or 0.08 to 0.10 per cent.

Sixth.—The pulling speed of the machine for breaking test pieces shall not be less than ½ in. per minute, nor more than 3 ins. per minute.

CLASS I.—Extra Dead Soft; for common rivets, wire cables, and other purposes where exceptional toughness is required.

Method of Manufacture.—Basic open-hearth process.

Chemical Composition, in per cent.—P below .04; S below .06; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
		Minimum.	Maximum.			
Rivet rods.....	⅝	46 000	55 000	64.0	28.0	52
"	¾	46 000	54 000	63.0	29.0	58
"	⅞	45 000	54 000	61.5	29.25	56
"	1	45 000	54 000	60.0	29.50	54
"	1¼	44 000	54 000	58.5	29.75	52
"	1½	44 000	54 000	57.0	30.00	50

A rolled round about ¾ in. in diameter, after being nicked about one-quarter way through, shall bend completely double without fracture, with the nick on the outer curve of the bend.

Heats rolled into bars less than ⅝ in. in diameter may be tested in trial rods of ¾ in.

If any bar fails to pass the physical tests, four more pieces shall be taken from the same heat and the average of all five bars shall be considered the true record.

CLASS II.—Bridge Rivets; for rivets in railroad bridges.

Method of Manufacture.—Acid or basic open-hearth process.
Chemical Composition, in per cent.—P below .04 in acid steel, below .03 in basic; S below .05; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 Ins. Per Cent.		Average reduction of area. Per cent.
		Minimum.	Maximum.		Average.	Minimum.	
Rivet rods..	⅝ to ¾	48 000	57 000	66.0	29.0	27.0	60
" ..	⅞	48 000	56 000	65.0	30.0	28.0	60
" ..	⅞	47 000	56 000	63.5	30.5	28.5	58
" ..	1	47 000	56 000	62.0	31.0	29.0	56
" ..	1⅛	46 000	56 000	60.5	31.0	29.0	54
" ..	1¼	46 000	56 000	59.0	31.0	29.0	52

Two tons of bars from the same heat shall constitute a lot, and two specimens, each from a different bar, shall be tested from each lot. The above table gives the average required of these two bars, and the minimum below which no bar shall fall. If the average elongation or reduction of area on any one lot shall fall below the requirement, two additional bars shall be cut from the same lot, and the average of the four pieces shall be considered the average of the lot, provided that no concession be made in the minimum. Heats rolled into sizes less than ⅝ in. may be tested in trial rods of ¾ in.

A rolled round about ¾ in. in diameter, after being nicked one-quarter way through, shall bend completely double without fracture, with the nick on the outer curve of the bend. A piece of ¾-in. rod cut ½ in. long shall be upset while cold into a disc ⅛ in. thick, without developing extensive flaws or showing signs of cold shortness.

CLASS III.—Hard Bridge Rivets; a substitute for Class II, giving greater strength with less toughness.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition, in per cent.—P below .04 in acid steel, below .03 in basic; S below .05; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 Ins. Per Cent.		Average reduction of area. Per cent.
		Minimum.	Maximum.		Average.	Minimum.	
Rivet rods..	$\frac{5}{8}$ to $\frac{7}{8}$	54 000	63 000	61.0	28.0	26.0	55
" ..		54 000	62 000	60.0	29.0	27.5	55
" ..		53 000	62 000	58.5	29.5	27.5	53
" ..	1	53 000	62 000	57.0	30.0	28.0	51
" ..	$1\frac{1}{8}$	52 000	62 000	55.5	30.0	28.0	49
" ..	$1\frac{1}{4}$	52 000	62 000	54.0	30.0	28.0	47

Two tons of bars from the same heat shall constitute a lot, and two specimens, each from a different bar, shall be tested from each lot. The above table gives the average required of these two bars, and the minimum below which no bar shall fall. If the average elongation or reduction of area on any one lot shall fall below the requirement, two additional bars shall be cut from the same lot, and the average of the four pieces shall be considered the average of the lot, provided that no concession be made in the minimum. Heats rolled into sizes less than $\frac{5}{8}$ in. may be tested in trial rods of $\frac{3}{4}$ in.

CLASS IV.—Common Hard Rivets; for roof trusses and other structures not exposed to shock.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .05; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
		Minimum.	Maximum.			
Rivet rods.....	$\frac{5}{8}$ to $\frac{7}{8}$	54 000	63 000	61.0	27.0	55
"		54 000	62 000	60.0	28.0	55
"		53 000	62 000	58.5	28.5	53
"	1	53 000	62 000	57.0	29.0	51
"	$1\frac{1}{8}$	52 000	62 000	55.5	29.0	49
"	$1\frac{1}{4}$	52 000	62 000	54.0	29.0	47

Four tests shall be taken from each heat, and the average of these four shall conform to the above table. If the average elongation or reduction of area of any heat shall fall below the requirement, four additional bars may be cut from the same heat, and the average of the eight pieces shall be considered the average of the heat. Heats rolled into sizes less than $\frac{5}{8}$ in. may be tested in trial rods of $\frac{3}{4}$ in.

CLASS V.—Soft Bridge Steel; for angles, plates, bars, etc., for bridges, cranes, and similar structures exposed to shock.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .60.

Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch. Minimum.	Ultimate Strength. Pounds per Square Inch. Maximum.	Elastic ratio.	Elongation in 8 ins Per cent.	Reduction of area. Per cent.	Remarks.
Angles ...	[illegible]	50 000	58 000	63.0	29.0	55	One piece of $\frac{3}{4}$-in. angle must open out flat and another close shut without sign of fracture.
" ...	[illegible]	50 000	58 000	61.5	29.0	53	
" ...	[illegible]	49 000	58 000	60.0	29.0	51	
" ...	[illegible]	49 000	58 000	58.5	29.0	49	
" ...	[illegible]	48 000	58 000	57.0	29.0	47	
Plates....	$\frac{5}{16}$	53 000	63 000	65.0	23.0	44	On plates under 42 ins. wide the required elongation shall be raised 1.5% and the reduction of area 2.0 per cent. On plates over 70 ins. wide the elongation shall be lowered 1.5% and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5% and 15 per cent. Both longitudinal and transverse strips cut from plates shall bend double flat. When every plate in the heat is tested, the minimum elongation and reduction shall be lowered 5 per cent.
"	[illegible]	51 000	61 000	63.0	26.0	50	
"	[illegible]	50 000	60 000	62.0	26.0	50	
"	[illegible]	49 000	59 000	60.0	25.0	48	
"	1	48 000	58 000	58.0	24.0	46	
"	$1\frac{1}{4}$	47 000	58 000	56.0	23.0	44	
Eye-bars annealed.	$\frac{3}{4}$	50 000	58 000	57.0			The elongation in full length shall be 15% in bars from 10 to 20 ft. long, 14% in 21 to 25 ft., 13.5% in 26 to 30 ft., and 13% in 31 to 35 ft.
" ..	1	50 000	58 000	56.0			
" ..	$1\frac{1}{2}$	49 000	58 000	54.0			
" ..	2	49 000	58 000	53.0			
" ..	$2\frac{1}{2}$	48 000	58 000	52.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

CLASS VI.—Medium Bridge Steel; a substitute for Class V when greater strength and less toughness are required.

Method of Manufacture.—Acid or basic open-hearth process.
Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .65
Physical requirements as follows :

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles...	¾	56 000	64 000	63.0	27.0	50	One piece of angle, not over ½ in. thick, shall open out flat, and another close shut without sign of fracture.
" ...	⅞	56 000	64 000	61.5	27.0	48	
" ...	1	55 000	64 000	60.0	27.0	46	
" ...	1¼	55 000	64 000	58.5	27.0	44	
" ...	1½	54 000	64 000	57.0	27.0	42	
Plates....	⅝	59 000	69 000	62.0	22.0	39	On plates under 42 ins. wide the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut cross-wise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5%, and 15 per cent. Longitudinal strips shall bend double flat; transverse strips shall bend through 180° around a pin 1 in. in diameter. When every plate in the heat is tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	⅞	57 000	67 000	60.0	25.0	45	
"	1	56 000	66 000	59.0	25.0	45	
"	1¼	55 000	65 000	57.0	24.0	43	
"	1	54 000	64 000	55.0	23.0	41	
"	1¼	53 000	64 000	53.0	22.0	39	
Eye-bars annealed.	¾	56 000	64 000	56.0			The elongation in full length shall be 14% in bars from 10 to 20 ft. long, 13% in 21 to 25 ft., 12.5% in 26 to 30 ft, and 12% in 31 to 35 ft.
"	1	56 000	64 000	55.0			
"	1½	55 000	64 000	53.0			
"	2	55 000	64 000	52.0			
"	2½	54 000	64 000	51.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08% for acid, and .05% for basic steel, if the best quality is not required, but other specifications must remain the same.

CLASS VII.—Hard Bridge Steel.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .80.

Physical requirements as follows :

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles ...	[illegible]	60 000	68 000	62.0	26.0	48	One piece of angle, less than ½ in. thick, shall open out flat, and another piece close shut without sign of fracture.
" ...		60 000	68 000	60.5	26.0	46	
" ...		59 000	68 000	59.0	26.0	44	
" ...		58 000	68 000	57.5	26.0	42	
" ...		57 000	68 000	56.0	26.0	40	
Plates....	⅜	63 000	73 000	60.0	20.0	34	On plates under 42 ins. wide the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5%, and 15 per cent. Longitudinal strips shall bend double flat. Transverse strips shall bend through 180° around a pin 1 in. in diameter. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	[illegible]	61 000	71 000	58.0	23.0	40	
"		60 000	70 000	57.0	23.0	40	
"		59 000	69 000	55.0	22.0	38	
"	1	58 000	68 000	53.0	21.0	36	
"	1¼	57 000	68 000	51.0	20.0	34	
Eye-bars annealed.	¾	60 000	68 000	55.0	The elongation in full length shall be 13% in bars from 10 to 20 ft. long, 12.5% in 21 to 25 ft., 12% in 26 to 30 ft., and 11.5% in 31 to 35 ft.		
" .	1	60 000	68 000	54.0			
" .	1½	59 000	68 000	52.0			
" .	2	59 000	68 000	51.0			
" .	2½	58 000	68 000	50.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08% in acid, and .05% in basic steel, if the best quality is not required, but other specifications must remain the same.

CLASS VIII.—Extra Hard Bridge Steel; for special structures where great stiffness is essential.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .80.

Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles....	[illegible]	64 000	72 000	61.0	25.0	45	One piece of angle, about ¾ in. thick, shall open out flat, and another piece close shut without sign of fracture.
"		64 000	72 000	59.5	25.0	43	
"		63 000	72 000	58.0	25.0	41	
"		62 000	72 000	56.5	25.0	39	
"		61 000	72 000	55.0	25.0	37	
Plates....	[illegible]						On plates under 42 ins. wide, the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut cross-wise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5% and 15 per cent. Longitudinal strips shall bend double flat. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	⅝	67 000	77 000	59.0	18.0	32	
"	[illegible]	65 000	75 000	57.0	21.0	38	
"	[illegible]	64 000	74 000	56.0	21.0	38	
"	[illegible]	63 000	73 000	54.0	20.0	36	
"	1	62 000	72 000	52.0	19.0	34	
	1¼	61 000	72 000	50.0	18.0	32	
Eye-bars annealed.	¾	64 000	72 000	54.0			The elongation in full length shall be 12.5% in bars from 10 to 20 ft. long, 12.0% in 21 to 25 ft., 11.5% in 26 to 30 ft., and 11.0% in 31 to 35 ft.
" ..	1	64 000	72 000	53.0			
" ..	1½	63 000	72 000	51.0			
" ..	2	63 000	72 000	50.0			
" ..	2½	62 000	72 000	49.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowances for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08% for acid steel, and .05% for basic, if the best quality is not required, but other specifications must remain the same.

CLASS IX.—Forging Steel; for pins and miscellaneous forgings and for special plates and angles.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .90.

Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate Strength Pounds Per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles....	[illegible]	70 000	80 000	58.0	22.0	42	One piece of angle ¾ in. thick shall open out flat, and another piece close shut without sign of fracture.
"		70 000	80 000	56.5	22.0	40	
"		69 000	80 000	55.0	22.0	38	
"		68 000	80 000	53.5	22.0	36	
"		67 000	80 000	52.0	22.0	34	
Plates....	⅝	73 000	83 000	56.0	16.0	30	On plates under 42 ins. wide the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. Longitudinal strips under ½ in. thick shall bend double flat. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	[illegible]	71 000	81 000	54.0	19.0	36	
"		70 000	80 000	53.0	19.0	36	
"	[illegible]	69 000	79 000	51.0	18.0	34	
"	1	68 000	78 000	49.0	17.0	32	
"	1½	67 000	78 000	47.0	16.0	30	

When this steel is used for pins or forgings, a charge may be tested by rolling a small test ingot or piece of bloom into a bar with a cross-section of about 0.5 or 1.0 sq. in. This bar should have an ultimate strength of between 70 000 and 80 000 lbs. per square inch, an elastic ratio of 58%, and an elongation of 15% in 8 ins. This method will usually suffice to show the quality of the steel. If it is desirable to test the forged work, a bar should be cut from a rolled or hammered piece about 6 ins. in smallest dimension, and turned to a ¾-in. round, 2 ins. between shoulders. This should have an ultimate strength of between 67 000 and 80 000 lbs. per square inch, an elastic ratio of 50%; and an elongation of 20% in 2 ins. The test piece should be cut at a depth of about 2 ins. from the outside.

CLASS X.—Hard Forging Steel; for miscellaneous forgings.

Method of Manufacture.—Acid or basic open-hearth process.
Chemical Composition in per cent.—P below .05 in acid steel, below .03 in basic; S below .10; Si below .10; Mn below .90.
Physical requirements as follows:

SHAPE AND ORIGIN OF TEST PIECE.	ULTIMATE STRENGTH. POUNDS PER SQUARE INCH.		Elastic ratio.	Elongation. Per cent.
	Minimum.	Maximum.		
A rolled bar with a cross-section of about 0.5 to 1.0 sq. in., made from a bloom or test ingot. Elongation measured in 8 ins	75 000	100 000	55	12
A $\frac{7}{8}$ in. round, 2 ins. long between shoulders, cut from a rolled or forged piece about 6 ins. in smallest dimension. Elongation measured in 2 ins	75 000	100 000	45	15

The first method will suffice for ordinary work to show the quality of the material. The second involves considerable expense and delay in cutting and finishing the piece, and there is necessarily much variation caused by the different sizes and shapes of forgings. The test pieces should be cut at a depth of about 2 ins. from the outside.

CLASS XI.—Common Soft Steel; for roof trusses and other structures not exposed to shock.

Method of Manufacture.—Acid or basic open-hearth process or converter.

Chemical Composition in per cent.—P below .10; S below .10; Mn below .65.

Physical requirements as follows:

SHAPE.	Thickness in inches.	ULTIMATE STRENGTH. POUNDS PER SQUARE INCH. Minimum.	Maximum.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	REMARKS.
Angles....		56 000	64 000	62.0	25.0	45	A ¾-in. hole punched in an angle, with its center 1¼ ins. from the rolled edge, shall stand drifting to 1¼ ins. without fracture.
" ...		56 000	64 000	60.5	25.0	43	
" ...		55 000	64 000	59.0	25.0	41	
" ...		54 000	64 000	57.5	25.0	39	
" ...		53 000	64 000	56.0	25.0	37	
Plates....	⅝	59 000	69 000	60.0	19.0	34	On plates under 42 ins. wide, the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the required elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut cross-wise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5%, and 15 per cent. Longitudinal strips shall bend through 180° around a pin 1 in. in diameter.
"		57 000	67 000	58.0	22.0	40	
"		56 000	66 000	57.0	22.0	40	
"		55 000	65 000	55.0	21.0	38	
"	1	54 000	64 000	53.0	20.0	36	
"	1½	53 000	64 000	51.0	19.0	34	
Eye-bars annealed.	¾	56 000	64 000	56.0			The elongation in full length shall be 12.5% in bars from 10 to 20 ft. long, 12.0% in 21 to 25 ft., 11.5% in 26 to 30 ft., and 11.0% in 31 to 35 ft.
" .	1	56 000	64 000	55.0			
" .	1¼	55 000	64 000	53.0			
" .	2	55 000	64 000	52.0			
" .	2½	54 000	64 000	51.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

CLASS XII.—Common Hard Structural Steel; a substitute for Class XI when greater strength and less ductility are required.

Method of Manufacture.—Acid or basic open-hearth process or converter.

Chemical Composition in per cent.—P below .10; S below .10; Mn below .85.

Physical requirements as follows:

SHAPE.	Thickness in inches.	ULTIMATE STRENGTH POUNDS PER SQUARE INCH.		Elastic ratio.	Elongation in 8 ins Per cent.	Reduction of area. Per cent.	REMARKS.
		Minimum.	Maximum.				
Angles ...	[illegible]	60 000	68 000	60.0	22.0	40	A ¾-in. hole punched in an angle, with its center 1¼ ins. from the rolled edge, shall stand drifting to 1¾ ins. without fracture.
" ...		60 000	68 000	58.5	22.0	38	
" ...		59 000	68 000	57.0	22.0	36	
" ...		58 000	68 000	55.5	22.0	34	
" ...		57 000	68 000	54.0	22.0	32	
Plates....	[illegible]	63 000	73 000	58.0	17.0	29	On plates under 42 ins. wide, the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the required elongation shall be lowered 1.5% and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10%. On universal mill plates, the allowance for transverse tests shall be 5 000 lbs., 5% and 15 per cent. Longitudinal strips shall bend through 180° around a pin, the radius of which is 1½ times the thickness of the plate.
"		61 000	71 000	56.0	20.0	35	
"		60 000	70 000	55.0	20.0	35	
"		59 000	69 000	53.0	19.0	33	
"	1	58 000	68 000	51.0	18.0	31	
"	1½	57 000	68 000	49.0	17.0	29	
Eye-bars annealed.	¾	60 000	68 000	55.0			The elongation in full length shall be 11.5% in bars from 10 to 20 ft. long; 11.0% in 21 to 25 ft.; 10.5% in 26 to 30 ft., and 10% in 31 to 35 ft.
" .	1	60 000	68 000	54.0			
" .	1½	59 000	68 000	52.0			
" .	2	59 000	68 000	51.0			
" .	2½	58 000	68 000	50.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

STEEL CASTINGS.

Method of Manufacture.—Acid open-hearth process.

Chemical Composition in per cent.—P below .04; S below .05; Mn below .80.

Physical requirements as follows:

Grade.	Shape and origin of test piece.	Condition of test piece.	Ultimate Strength, Pounds per Square Inch.		Elastic ratio.	Elongation, Per cent.
			Minimum.	Maximum.		
Soft	½ in. round, 2 ins. between shoulders, cut from a coupon or casting	Annealed	54 000	64 000	50	20
		Natural	57 000	67 000	50	15
	A round or flat test piece, rolled from a small test ingot of the heat from which castings are made. Tested in 8-in. length	Natural	58 000	68 000	55	20
Hard	½-in. round, 2 ins. between shoulders, cut from a coupon or casting	Annealed	60 000	70 000	50	15
		Natural	63 000	73 000	50	15
	A round or flat test piece, rolled from a small test ingot of the heat from which castings are made. Tested in 8-in. length	Natural	64 000	74 000	55	15

NOTE.—No record shall be kept of test bars exhibiting imperfections.

Recommendations.—It is recommended that the rolled test bar ("preliminary test") be used as a rule, and that the expense of cutting a piece from a casting be resorted to only occasionally as a check. Also, that castings of simple form be used without annealing. Also, when a large number of similar pieces are to be made, that special bending or drop tests be devised, such tests, together with the chemical analysis, to be the sole requirements.

DISCUSSION.

GUS. C. HENNING, Esq.—The proposed specifications have evidently been carefully prepared and systematically arranged, and are admirably drawn, as a rule, to suit the product of the basic open-hearth furnace. Exception should be taken, however, to a number of statements in Mr. Henning.

Mr. Henning. the preliminary paragraphs preceding the classification proper of the different kinds of material.

The author states: "It is certain that the ordinary systems of testing fail entirely to distinguish the product of the open-hearth from that of the Bessemer converter." The speaker believed that the microscopical examination of the structure of specimens may be considered among the ordinary systems of testing and it readily distinguishes the methods by which steel is manufactured. The author states further: "Notwithstanding this fact there is good testimony to show that the product of the converter is an inferior metal, which gives way in a treacherous manner under shock." No data or instances are given to justify this broad statement, and in view of this the speaker stated that he had met with cases of accidental fracture of angles and channels of Bessemer and open-hearth steel which showed invariably that the failure was not due to the steel but to the heat treatment the metal had received, the fractures showing a coarse, crystalline structure such as soaking or overheating will produce.

During the inspection of the shop-work of the superstructure of the East River Bridge, both shapes and rivets failed repeatedly, and the most careful chemical analyses and physical investigations never revealed any differences in composition, while the fractures themselves plainly showed the cause of rupture to be overheating. Also while the shop-work on the Blair and Henderson Bridges was being inspected, similar accidents occurred, which, as before, could not be attributed to the character or quality of the steel, the fractures showing plainly that the materials had been overheated. It must be borne in mind that in these cases, the first being Bessemer and the last open-hearth steel, the trouble occurred in thin shapes only, $\frac{5}{16}$ in. or less in thickness. Examples of even worse failures than these were steel eye-bars which had been tested to destruction, the defective bars invariably showing overheating, caused by the anxiety of the forge gang to earn large wages. They knew that eyes could be formed readily and rapidly by heating the bars to a very high heat, in fact to a temperature which just caused the edges of the bars to melt. This ruined them by overheating, as they all failed in the neck or eyes, showing coarsely crystalline fractures. The speaker had never yet seen a case where failure of any shape steel while being punched was not due to bad furnace treatment, neither had he found recorded any evidence of difference in the character of the material at the point of fracture from that at other points of the same bar. Moreover, as no impact tests comparing Bessemer and open-hearth steel are in existence, the broad statement by the author that "the product of the converter is an inferior metal which gives way in a treacherous manner under shock" is entirely unwarranted.

The author states also that the only safe way to avoid accident is to

use open-hearth steel. The speaker asked whether the propriety of using Bessemer steel for rails had ever been questioned, and further, if there were not several million tons of Bessemer steel rails in use on the more than 150 000 miles of railways in this country, and if these were not subjected to much severer shock than any member of a bridge. Mr. Henning.

The author asserts that copper has no appreciable influence on the strength and ductility of steel, but the speaker said that a large percentage of copper increases materially its ultimate strength and ductility, as wire manufacturers have learned. He also asked for proofs of the author's statement: "For just as it (manganese) resists the separation of the crystals in cooling from a liquid state, so it opposes their formation when a high thermal altitude augments the molecular mobility."

In Table No. 3, a series of tests are given which purport to represent the behavior of steel under shock, but the speaker could not agree with the author that these tests do this. The shock is none such, in the first place, and is applied at right angles to the initial strain. Shock cannot really be produced by a copper hammer, which is purposely made of very soft pliable metal, so as not to apply sudden intense strains to the harder and more elastic material on which it is used. Moreover, shock in order to be effective should be applied in the direction of application of the initial load, in order to show its effect on the metal under investigation.

The author says of phosphorus: "For common structural material, the critical content has been placed by general consent at 0.10%, but this is altogether too high for railroad bridge work." In view of the fact that thus far no bridge has ever failed or given the slightest cause for alarm on account of the phosphorus content of the steel, the speaker held such a statement to be hardly justified. He also considered that the author does not present the facts concerning physical properties in exactly the proper manner. The strength of steel in a $\frac{3}{8}$-in. plate is compared with that of a $\frac{7}{8}$-in. angle, supposing them to be rolled from the same ingot. This he believed to be neither just nor proper. The principal aim of an engineer must be to build a bridge which is constructed of a material uniform in quality, no matter in what shapes it be used. Chords, posts and struts, as well as floor beams and stringers, must be built up of shapes of various dimensions, but as they should work as units the material should be uniform. Angles, channels and plates are never rolled in the same set of rolls. The ingots are rolled and cut into suitable blooms and distributed to various points of a works for finishing. It is, therefore, no hardship or difficulty for a mill to select ingots for shapes according to the finished dimensions, basing such a selection on the preliminary test, which is always a sufficient guide for a competent mill man. There is no reason why an engineer should accept a hetero-

Mr. Henning. geneous lot of stuff, simply because it allows the blooming mill to cut up its product indiscriminately according to the weight of finished pieces. Sometimes, it is true, there will be a quantity of stock left over which cannot be used immediately and must be stored, but as every works office first tries to utilize all stock on hand, having a correct list of quality and size of pieces (blooms), this becomes a simple matter. Now, the rule is that steel made for angles is not used for plates, and *vice versa*, although steel intended for bars and angles is frequently the same, because mill men know that the finished shapes will have very similar qualities. In Europe, where material is tested in its finished shape only, and never in the shape of preliminary ¾-in. rounds, the question of expense has never been raised, and their bridges do not cost as much per pound as American structures. Nor does steel in Europe cost more per pound than here, although always tested in finished shapes. It is quite certain that the steel-maker never bears the expense of testing, for that is always taken into account in making a price.

It did not seem reasonable that material of variable quality should be accepted by engineers because one kind will not show the same qualities in all thicknesses. It seemed much more reasonable that a contractor, knowing the requirements, should arrange for the manufacture of his product in such a way that with intelligent supervision a uniform result will be secured.

An inspector should devote his entire attention to the quality of the finished product, and leave all preliminary tests to the mill men; that is their business alone. Those who know how easily the quality of steel can be modified by careful and proper heat treatment will bear out this statement.

The author attempts to show the influence of the shape of the test piece on results obtained; and to do this he has had ¾-in. rods and 2 x ⅝-in. flats rolled under similar conditions, and then tested. The differences found are then ascribed to shape alone. This did not seem at all proper; these shapes were neither similar in periphery, in scantling, in amount of work done upon the billet, and it is not certain that the finishing temperatures were identical. The differences in the results, however, are so slight that he thought it would be very hazardous to say to what they might be due. Then in comparing these tests with those of similar bars, described as annealed, it seemed certain that all of these bars were too highly heated, and not properly annealed; the results of tests of these bars indicate this very clearly, and hence the accuracy of the statements made, based on them, may be questioned. In a paper by the speaker, published in the *Transactions* of the American Society of Mechanical Engineers, Vol. XIII, p. 572, he showed what effect proper and improper annealing had on structural steel. While proper methods produce beneficial results,

such inferior results as those quoted by the author lead to the belief that these test bars were raised to a very high heat, about to yellow color. The difference between these annealed and natural tests were not thought by the speaker to show differences due to rolling, as is indicated by Table No. 8. The author's tests on relative elongation are very valuable, although they are only corroborative of a vast amount of work done and published. The Committee on Standard Tests of the American Society of Mechanical Engineers has given* a full explanation of this variation of elongation, and a number of papers on the subject are to be found in the publications of various engineering societies. In these various papers it is definitely proved that at the maximum load carried by any test piece the percentage of elongation is absolutely uniform, no matter what length of test piece is used; and that the varying percentage of elongation after rupture is solely due to local distortion at the point of fracture. Hence, if this local elongation be deducted from the total, the remaining elongation will always be proportional to the length of the test piece. Mr. Henning.

The author says that variations in the width of the test piece have little effect upon the reduction of area, but a slight deterioration is indicated with increase of width. The speaker claimed that if greater width had been chosen and tested, the author would have found that width materially affects reduction of area, and that the tests made lie within those limits which do not fairly show this effect.

Exception was also taken to the author's opinion: "A softer metal than is often employed should be used for bridges, because although a slight sacrifice is made in the ultimate strength this is partly offset by the higher elastic ratio and a decided increase in toughness and resistance to shock," which statement, as shown in a paper† on impact tests of steel by Professor Martens, of Berlin, could not be substantiated.

Under "Class I, Dead Soft," the author includes steel for wire cables, but the qualities prescribed by the tests are not those of a satisfactory cable wire. The speaker believed that entirely different tests should be applied to determine the suitability of any steel for wire cable, and said that it is well known that the softest wire is by no means the most suitable for wire cables, but that a hard wire will give much greater service and life. He recommended Mr. J. B. Stone's continuous bending tests. It seemed to him that, inasmuch as all rivet steel is to be subjected to high heat while being formed into rivets and again while driving them in work, an additional test should be prescribed, and this to each and every rod, viz., "to bend one end of each and every rod around a square corner." This will determine whether

* See the *Transactions* of the American Society of Mechanical Engineers, Vol. XIII, p. 289.

† Published in the *Transactions* of the Royal Testing Laboratory at Charlottenburg, Berlin.

Mr. Henning. any rod has been slightly overheated, as such a rod will show cracks while bending, and at the same time the test will cull rods which are split or piped. In half a day a great many tons of rivet rods can be thus tested; hence it will not add materially to the cost.

The principal and only serious objection to be made to these specifications, in his opinion, was the following: That while the steels defined by Classes I to VI and Class IX are made easily and cheaply by the basic open-hearth process, those described in Classes VII to XII, excluding Class IX, cannot be produced with unvarying certainty or uniformity by it; and that, while Classes VII to XII, excluding Class IX, can be made cheaply and uniformly by the acid open-hearth process, the remainder cannot be made easily, regularly and economically by it. The experience had with the open-hearth process is this: That while the acid process is most suitable and economical for steels having a tenacity of 60 000 lbs. or more, the basic process is most reliable and economical in the production of steels having a tenacity of less than 60 000 lbs. The experience on the continent of Europe, where makers are dependent upon low-grade ores, and where steel-making was not economically very successful until the introduction of the basic furnace, is that this process is the cheapest and most reliable for working their materials, but is not uniformly reliable in producing higher carbon steels, and in fact that sufficient experience has not been had with it to produce a uniform quality of such material.

On the other hand, the acid open-hearth process is most serviceable in the production of high-carbon steels, but is not so reliable in producing a steel very low in carbon, adding materially to the cost of production and not producing uniformly satisfactory results, besides requiring increased watchfulness and attention.

Therefore, in these specifications the speaker considered Classes I to VI and IX should preferably be made by the basic process, while VII to XII excepting Class IX, should be made by the acid open-hearth process. The author's contention that Bessemer steel should be excluded entirely cannot be agreed to, as this would be a great injustice to a number of reputable establishments which have always produced a reliable Bessemer product. The author's assumption that the very soft and weak steels, which he defines, should be used at least as much as stronger steels, may be correct when referring to small structures where increased dead weight does not materially increase the cost; but it does not seem to hold good in the case of a large structure, where the dead weight to be carried is always many times that of the live load, and really determines the cost of the structure. As there is no difficulty in obtaining very strong steels of absolute uniformity, and as many shops are well able to handle such material properly, at a price only a little above that of very low steels, there will be in many cases no justification for the use of the latter. If there were any

scarcity of high-grade materials to produce these high steels, as there is in Europe, there would be reason for discrimination against the latter. As our country, however, furnishes ample supplies of raw materials for all grades of steels, our engineers should always use their discretion in selecting the most suitable material for the particular structure in hand, instead of being guided entirely by the pound price of the steels offered by the makers. Mr. Henning.

FREDERICK H. LEWIS, Esq.—As a part of practical working specifications, it is not likely that the draft in the paper as prepared will commend itself, although for the facts set forth and the many suggestions developed, the paper is undoubtedly a most valuable contribution. Mr. Lewis.

The author seems to have been over-liberal in some respects, being willing to grant more in the way of chemical requirements for steel than engineers have previously thought it necessary to ask. For instance, we have been led to believe by metallurgists of high standing that a phosphorus percentage of 0.08 as an average, with a maximum of 0.10, was all that could reasonably be asked for in the regular grade of acid open-hearth steel, and that to tax this product with more stringent requirements would increase the cost so much as to debar it from competition with Bessemer or basic steel. Manufacturers who are making strictly acid steel, and have no basic furnaces to supply low-phosphorus stock, will certainly find it difficult to meet the phosphorus percentages suggested. If the author's phosphorus percentages for acid open-hearth steel are adopted, it is likely to be legislated out of existence.

Again the specifications are open to criticism for giving too great a scope to basic steel. As a soft steel, there can be no doubt that the basic product is a superior metal. But it is found that the low-phosphorus percentages which are such a valuable feature of this product require high figures for carbon. Thus in moderately heavy sections, it is found that an ultimate strength of 60 000 lbs. in basic steel requires generally from 0.23 to 0.25% carbon, and rather frequent failures to stand the quenching test are found in basic steel giving these figures on ladle analysis. It is quite certain that engineers will not give much scope in structural work to a steel which will temper, or, in other words, which fails, in the quenching test. To suggest basic steel with a tensile strength above 64 000 lbs. for structural work does not seem to be well advised, especially when the vagaries of the recarburizing process are considered.

Some facts are developed in the paper in regard to how tests are obtained—the science of producing tests. A great deal more might be said on this subject, but the author has clearly outlined the principles which have been followed in this study. He says in connection with it that inspectors have been a party to these methods to some extent and that this course is creditable to them. This statement is not

Mr. Lewis. likely to pass unchallenged. Clearly an agent who withholds facts or who in any way tampers with them is treading on dangerous ground. In the present case, however, there is one important consideration to justify such action, viz., that an inspector in these cases is dealing with conditions which the specifications do not recognize and with facts which the profession has not admitted and is apparently not yet prepared to admit. Under such circumstances, inspectors probably are justified in assuming their own judgment to be the best guide.

The conditions of tests and the methods of testing are things which engineers can regulate in conference, and there is nothing at the present time more important than a deliverance from the American Society of Civil Engineers on "Standard Methods" for testing steel. The specifications to-day assume (1) that steel is homogeneous, and that it does not make any difference where the test piece or sample is taken; (2) that there is no difference in results in tests from different sections; (3) that there is no difference in tests due to the preparation of test pieces; and (4) that the regimen of the testing machine has no effect on results. None of these assumptions is true or even approximately true.

It is disappointing to find comparatively little in the paper about segregation. The available data on segregation is unfortunately small, but what there is of it shows that 25% increase in carbon and phosphorus may be expected in good practice and occasionally much higher figures. As tests are now made, they are intended to represent the average quality of the metal and in fact generally do represent the better part of it. This is fair enough, no doubt; but as entire melts are accepted for use, it is certainly logical to ascertain what the material is like at its worst. Of what use is it to file results showing a soft ductile material with percentages of elongation in the neighborhood of 30, when it is evident that a test piece selected on a different principle might not show 20% elongation?

The author states that a percentage of 0.12% phosphorus in steel would be criminal. If he means that percentage to be a maximum, then it may be confidently asserted that our structures contain many such crimes.

The preparation of tests and the methods of testing undoubtedly affect results to a considerable extent. The author shows that the greater the width, the greater the stretch in 8 ins., and gives formulas which have been devised by different parties to represent this fact. None of these formulas, however, amount to anything, and a common-sense explanation of this simple fact may not be amiss. It is this: It has been agreed to use an 8-in. length in which to measure the elongation of test pieces. It will be found by examination that in the draw-down adjacent to the fracture the percentage of stretch in soft steel is in the neighborhood of 50, while beyond these curves to the gauge limit on either side the elongation is only about 20 per cent.

Mr. Lewis.

The effect of increased width, then, is simply to increase the length of the curves which constitute the draw-down to the fracture, or in other words to increase the length in which there is a high percentage of elongation. The difference in elongation due to the width of the specimen may be approximately given as follows for the same material:

For width of	1	in.	.....	25	per cent.
" "	2	"	.....	27	"
" "	3	"	.....	30	"
" "	4	"	.....	34	"
" "	5	"	.....	38	"
" "	6	"	.....	42	"

Without submitting detailed evidence on this point, attention is called to Table No. 15, which shows as an average of over 800 tests of full-sized eye-bars that the elongation at the fracture was 35½% in 12 ins. This would be quite 40% in a gauged length of 8 ins. To eliminate this difference in results requires a limit to the width of specimens, and not a limit in area.

The author gives a table showing a difference in elastic limit in the same steel from 39 000 lbs. at a slow testing speed to 46 000 lbs. at a rate of a 4½ ins. fall of pulling-head per minute, this latter being about the standard speed now in use in testing at the rolling mills. Just what view he takes of these figures is not clear, but apparently he regards it as an actual change in the elastic limit of the material. Such a view is certainly not tenable. Mr. Estrada gives some reason to think that the elastic limit is variable under shock, but he gives figures which are lower than was expected. There is nothing whatever to justify a belief that a comparatively small change in the rate of motion of the pulling-head of a testing machine would affect the actual elastic limit of the material in any way, much less to the extent of 15 to 20 per cent. Undoubtedly the lower figures reported give the correct elastic limit of the specimen. The determination of elastic limit by the fall of the beam is based entirely on the idea that when the test piece stretches faster than the fall of the pulling-head, the strain will relax, and the beam fall. At the slow speed which was customary when this method was adopted, the determination of the elastic limit in this way was correct, but it is perfectly clear that when higher rates of speed are used, it is possible to pass directly through the true elastic limit of the specimen and obtain a fall of the beam at some point beyond where the stretch of the specimen becomes greater than the speed of the pulling-head. The fact is that there is no way of determining the elastic limit except by testing slowly. This is quite as true of automatic devices as it is of the determination by the fall of the beam. It is, however, quite impracticable to make mill tests for the reception of structural material, without running testing machines at high speed. If the mills are run for great outputs, the testing machines must keep pace with the product; and as a high testing speed

Mr. Lewis. gives reasonably correct and comparable results for ultimate strength, for elongation and for the character of the fracture, no objection should be made to it, but it should be recognized as a fact that the elastic-limit determinations are not correct and not comparable. Nearly all the figures are considerably inflated for the reasons explained above, but in different degrees depending upon the regimen of machines.

On this matter of elastic limit the paper develops a remarkable difference between the views expressed in the draft of specifications and the facts which were brought forth at the outset to support these views. It will be found in the specifications that the author suggests elastic ratios as low as 47%, but in the record of tests which he submits, no elastic ratio below 62% is found in unannealed specimens. It is a little hard to see how he can justify his low elastic ratios in the specifications in comparison with the high elastic ratios submitted in his data, and he unquestionably owes some explanation on this point. That the specifications are measurably in accord with the real facts the speaker fully believed, but, if so, what then are we to think of the tests quoted?

The following table gives the results of some careful determinations of elastic ratios in soft steel of different thicknesses. These tests were made by the speaker with special care to have the figures correct.

Ultimate Strength.	Elastic Limit.	Thickness.	Elastic Ratio.
Pounds.	Pounds.	Inches.	
54 200	27 280	.805	50.0
58 030	30 950	.663	53.0
60 200	34 600	.550	57.5
61 720	34 270	.550	55.5
58 600	32 780	.505	56.0
55 620	33 290	.427	60.0
62 390	37 340	.375	60.0
59 240	37 870	.365	64.0
62 650	38 875	.315	62.0
60 360	40 890	.245	68.0
57 200	36 060	.225	63.0

In view of the errors in elastic-limit determinations, the speaker favored abandoning these determinations in regular tests made for the reception of steel at the rolling mills and substituting instead occasional determinations in laboratories where facilities can be had for making such determinations accurately.

The absolute requirements of specifications are matters of agreement between the contractor and the purchaser. What is needed to-day in testing steel is not new tests or more severe tests, but rational methods in testing and a recognition of conditions in the material tested. It has been made perfectly clear to intelligent men within the last few years that under the specifications as they stand, a great deal of testing is done which is purely conventional. Something has been done, perhaps, to improve the quality of steel, but a great deal more to develop the science of getting out tests.

CORRESPONDENCE.

SAMUEL TOBIAS WAGNER, M. Am. Soc. C. E.—Just how far specifications should go toward giving requirements for the chemical composition of steel is a hard point to decide, and generally what might be called the most severe specifications have gone past what seems to be a reasonable boundary; and, after giving in full the physical requirements, have proceeded to practically cover the chemical composition besides, thus binding the manufacturer in on all sides. Mr. Wagner.

It would seem, at first sight, that the present paper approximates this limit by specifying, besides the phosphorus, maximum limits for sulphur, silicon and manganese, and the advisability of going so much into detail is questioned. For all practical purposes the sulphur is regulated in the process of manufacture, as is clearly set forth in the paper, and for the reasons given in another place, it would seem that both the silicon and manganese could also be omitted in the specifications without practical detriment to the resulting metal. The necessity of specifying the maximum limit of phosphorus is unquestioned, as is also the advisability of not specifying the carbon content.

The writer would like to hear from the author as to whether he considers that a minimum limit of phosphorus should be specified on the grounds that a little is better than none.

The writer's attention was first called in 1883 to the difficulty of obtaining anything like uniform results from a heat of steel which was rolled into greatly varying sections,* and his attention was then drawn to the sliding scale in use at that time by the French navy to overcome this difficulty. It is questionable, however, in view of the amplification required in the specifications for ordinary structural work, whether it is advisable to use such a sliding scale for varying thicknesses, or to leave the matter to the judgment of the inspectors in selecting the tests, as is done at present.

The question of the rate of speed in the testing machine upon the results of the tests has always commanded interest, while never being recognized as of any vital importance. As pointed out in the paper, however, there is a necessity for uniformity of results, and some convenient rate of speed, as high as is consistent with accuracy of results, should be established.

The method of making tension tests in Scotland is to pull the specimen as rapidly as possible, and generally in a lever machine without attempting to measure the elastic limit. In this manner as many as 60 tests have been broken in an hour, including the time necessary to measure the specimens, put them in the machine, take them out and

* See the "Report of the Naval Advisory Board Upon Mild Steel Used in the Construction of the *Dolphin*, *Boston*, *Atlanta* and *Chicago*," 1886.

Mr. Wagner. record the result. While this seems to be much too fast, all tests are made at practically the same speed, and the results are comparable. The care taken in the preparation of the specimen, as far as the finish of the machined surface is concerned, is much less than that given in America.

The advisability of using a steel with an ultimate tensile strength of from 50 000 to 58 000 lbs. per square inch deserves careful consideration, but as a steel, say, from 56 000 to 64 000 lbs., is much stronger and is known to be a good, ductile and satisfactory metal in every particular, it would seem a sacrifice of strength for the sake of very little in return.

The writer thoroughly agrees in confining the use of steel for structural purposes to the product of the open-hearth furnace, whether the lining be acid or basic. His reasons for thus excluding the product of the Bessemer converter are based upon mysterious breaks in angles, plates and beams during treatment in the shops, when the only evidence of inferiority that could be found from the most careful investigation, chemical or physical, was that the metal was of Bessemer origin.

Mr. Lund. GEORGE A. LUND, Assoc. M. Am. Soc. C. E.—Nearly all the data and suggestions furnished by this paper seem to apply more particularly to bridge specifications than to steel used for building purposes. A few figures compiled from actual tests, showing the action of steel under a compressive strain, would be of great value. The largest part of the steel used in the construction of tall buildings and framed structures subjected to quiescent loads is employed in the shape of columns and beams. There is to-day, and probably will be, a continually increasing demand for this kind of material. The manufacturer should aim, therefore, to acquire a quality of steel for this purpose that can withstand a compression equal to cast-iron and still be of such toughness as to permit of punching and riveting without affecting in any way its durability and reliability. This would enable the engineer who favors steel-riveted work to compete with those employing cast-iron construction, and would eventually give a vast amount of trade into the manufacturer's hands. Steel for this purpose should have an ultimate strength of 70 000 to 80 000 lbs. per square inch in tension.

There is, also, one other feature that the engineer should not lose sight of. He should aim to secure a steel that can resist corrosion for a long period of years, without serious reduction of area. Most of the steel used in building, when once in place, is entirely covered, so that no opportunity is left for inspection and painting. Just what alloy of steel is the most durable under exposure may be an open question. It is, however, the opinion of many that a steel with a large percentage of carbon is most desirable.

ALFRED E. HUNT, M. Am. Soc. C. E.—An intelligent specification for structural steel as made to-day should prescribe the mode of manufacture as well as the composition of the metal, as stated in the paper, and the open-hearth method of manufacture of steel is preferable for the best grades of structural steel, although a very large amount of excellent quality Bessemer steel is made annually for structural purposes. Basic open-hearth steel has proved to be as good as that made upon the acid open hearth for many purposes, but it is worth noting that the author, as a manufacturer of basic open-hearth steel, concedes the desirability of requiring a lower percentage of phosphorus in the chemical composition of such material over acid open-hearth steel. The manufacturers of basic open-hearth steel in this country have strenuously opposed this, claiming it to be an unjust discrimination against this material. This, however, is not the fact in the case. Basic open-hearth steel, well made, will show a content of phosphorus below 0.04%, unless special precautions are made to add high-phosphorus materials in the ferro-manganese or other final additions in the manufacture of the metal. Under ordinary conditions, steel made by this process in this country, which contains over 0.04% phosphorus, affords an indication that it has not been well made, and that the basic operation has not been satisfactorily conducted, that the basic slag has not performed its function of carrying out the phosphorus as tri-basic phosphate of lime, as it should do. With acid open-hearth steel, the higher percentage of phosphorus contained is not such an indication that the steel has not been properly made. A large amount of excellent acid open-hearth steel is furnished with a maximum 0.08% phosphorus; but a basic open-hearth steel with 0.05 or 0.06% phosphorus should be regarded with a great deal of suspicion, and the writer would want to know what the conditions were which allowed such a high percentage of phosphorus to be contained in the metal, before accepting it for structural purposes. Mr. Hunt.

For purposes where the metal has to withstand violent impact, he prefers to place a higher unit strain upon the soft bridge steel of Class V, with a tensile strength of 50 000 to 58 000 lbs. per square inch, than upon the hard bridge steel of Class VII of the classification in the paper.

With the phosphorus largely eliminated from the metal as made by the basic open-hearth process, in order to get the tensile strength of hard bridge steel of Class VII, it has been found necessary to recarburize the metal considerably, adding difficulties of non-homogeneity of the recarburizing materials and of not giving as tough and ductile a metal, but of giving one which is much more susceptible and liable to inequalities due to cold rolling or otherwise hardening of the metal.

The writer's experience has confirmed the statements given in the paper as to the inert action of a considerable percentage of copper in

Mr. Hunt. structural steels; a proportion up to nearly 0.25% has not been found to injure the metal materially.

The position taken by the author in his paper regarding the difference between "elastic limit" and "yield point" is hard to understand. Defining the elastic limit in tension tests as the point where the increments of extension are no longer proportionate to the increments of strain, the elastic limit as ordinarily obtained in commercial testing is not accurately determined; and while the author's opinion of the value of the "elastic ratio" as one of the qualities of structural steel may be accepted, it is necessary that one of the terms of this ratio, the elastic limit, should be more accurately obtained than is now ordinarily done in practice.

The results of Table No. 17 show the marked difference which can readily be obtained in determining the elastic limit by varying the speed of the testing machine. This, however, is only one of the considerable number of factors by which the determination of the elastic limit can be and is manipulated by the skilled operators of the testing machines employed by the various steel works in commercial practice.

The statements that the elastic ratio and reduction of area decrease with increasing thickness of test specimens, while the elongation remains the same, are to be accepted as correct.

The writer is quoted as advocating the preliminary tests as a method of accepting or rejecting structural steel, that "it is convenient and that it is the fashion," and that he would recommend the acceptance of steel on preliminary tests, "provided that the finished material comes within 4% of the standard thus obtained." Attention is called to the fact that the paper from which the quotation is made was written five years ago, and that the writer cheerfully accedes that the "fashion" referred to has now been entirely changed. He does not think, however, that the author's position that this provision is a *reductio ad absurdum* is consistent with his making practically the same provisions for steel castings. The leaving out of preliminary tests as a requirement for structural steel has been a wise one, provided a suitable number of other tests of finished material are substituted for them. The preliminary tests should be left to the domain of the manufacturer, granting the engineer the right to do as he wishes in his test of the finished material.

The reasonableness of the stipulations of the author's specifications for a variation and concession in the requirement of tensile strength made for varying thicknesses and widths of section is conceded, but his arguments as to the honesty of the methods described of selection of test specimens in important plate work to meet the requirements of rigid specifications, are questionable. The rigid system of tensile requirements now called for in some instances is a reason for, if not a justification of, the practices and "expedients" which the author

admits are "dangerously near the line of deception" adopted by plate rollers to meet the specifications. The important public developments of the past few years as to methods of testing and obtaining test specimens should teach a lesson to engineers not to make rigid requirements of a kind that tend to demoralize mill employees regarding specifications. Mr. Hunt.

In the specification for rivet steel a further test always found satisfactory should be added, viz., to have the rivet steel to be tested actually made up into rivets and riveted up, the requirement being made that the rivets should cut out tough and strong with a cold chisel. This is a practical test, in most cases easily made, and one which in the writer's experience has often caused rejections of steel which otherwise would have been accepted, it being shown that the metal would not stand the punishment of riveting without becoming crystalline and brittle, even though the requirements of the steel would fall within the specification of Class II of the author's specification.

In Class V of soft bridge steel, the writer would recommend the phosphorus in acid open-hearth steel being a maximum of 0.08% instead of 0.06%, not that 0.06% is not a better requirement for steel than 0.08%, but because of the fact, which is plainly stated by the author, who is a basic as well as an acid open-hearth steel manufacturer, that "it must not be forgotten that it cost more to make pure metal by the acid than by the basic process," and that there is a large amount of good structural steel that would be excluded by the maximum requirement of 0.06% in acid open-hearth steel. This requirement of 0.06% phosphorus would be practically handicapping the acid open-hearth manufacturers in their competitive work with the basic open-hearth manufacturers.

On the other hand, if the requirement for sulphur were made, he would suggest a lower maximum than 0.1 per cent. A maximum of 0.06% of sulphur would be better.

A. C. Cunningham, M. Am. Soc. C. E.—The statement that different kinds of steel cannot be told the one from the other by analysis is doubtless true when all have the same chemical composition, but when the analyses and physical properties are considered collectively, one kind can be told from another in the majority of cases. In the case of an attempted fraud to substitute one kind of steel for another, the first consideration must be the securing of the specified physical properties in a specimen tension test, and where these correspond for the different kinds of steel, the nature of the different processes causes a variation in the chemical composition which would be detected by a practical observer. Should the fraud be carried so far as to secure a correspondence of chemical as well as physical results, it would defeat its own end in the increased cost. Mr. Cunningham.

The accidental mixture of different kinds of steel is readily told

Mr. Cunningham. from a consideration of the chemical and physical properties. The plea that engineers should enforce their specifications as to kind and quality of steel specified cannot be urged too strongly. Vacillation and caprice in this respect have a most serious moral effect upon the entire subsequent work; the honest competitor gives some serious study to his motto, "Honesty is the best policy," and wonders if he will have to turn it to the wall; the "concession hunter" is sorry he did not ask for more, and resolves to have it all his own way the next time, and the inspector sees the few weapons that he had for the protection of his principal taken from his hands, for while the kind of steel specified has been changed, nothing else in the specification has, and everything becomes discordant.

In addition to the serious moral effect in conceding a cheaper for a more expensive steel after a contract is let, an actual increased profit is likely to accrue to the contractor, the legitimacy of which is questionable. An engineer would resent it as an insult if asked to change his plans. Is it any less an insult to be asked to change his steel?

In the matter of sulphur the author has been rather too liberal. He recognizes the importance of low sulphur in rivets, but has overlooked the fact that eye-bars are also subject to several reheatings in the course of manufacture, and that the sulphur is of as much importance in the eye-bar as in the rivet.

Steel may be considered as having two sulphur limits, the safe limit, which concerns the engineer, and the economical limit, which concerns the manufacturer; beyond the economical limit of sulphur the loss in rolling more than counterbalances the cheapness of the original stock, and an occasional experience keeps the manufacturer within the economical limit.

From some experiences of the writer he believes that near the economical limit there is a dangerous point for sulphur which may lead to serious results. If the sulphur is sufficiently high to make the material break up in rolling, that is the end of it; but if it is at a point that will just permit the material to finish without visible flaws, it may still be appreciably injured for use.

The wording of the fifth clause under general provisions might cause complications in some instances. Should an engineer decide to have his analysis from the finished material, it is possible that no preliminary analysis would be made, and in the case of Classes XI and XII he might find himself forced to accept steel having 0.15 phosphorus and 0.15 sulphur, or at the best be put to considerable trouble and expense to reject it. This is an extreme case, but it is the extreme cases that cause difficulties.

Mr. Waddell. J. A. L. WADDELL, M. Am. Soc. C. E.—Such papers as this are of the greatest importance to all bridge engineers, more especially to

those who have no connection with shops, for the reason that they have to base most of the requirements of their specifications in respect to structural steel upon information which comes to them at second hand. As the manufacture of steel is still in the process of evolution, the consulting bridge engineer has to be changing his specifications continually. It is no exaggeration to state that during the last seven years the writer has made no two sets of specifications alike; starting in with the manufacturers' standard specifications as a basis, he has altered, amended, added to and erased from these, until the latest set, that for the Northwestern Elevated Railroad of Chicago, bears hardly any resemblance to the original. Unfortunately the end is not yet, for recent improvements in the manufacture of basic open-hearth steel, and probably future improvements also, will cause the process of evolution just mentioned to be continued for an indefinite time. "Unfortunately" is used perhaps unadvisedly, because substantial improvement is never to be deplored, although systemization of specifications is a great desideratum. Mr. Waddell.

If the principles enunciated in the paper be accepted without modification, all of the existing specifications for structural steel will have to be changed, in order to bring them up to date. It may be well, however, to await a thorough discussion of the paper by those interested in the subject, more especially engineers who are making a specialty of inspecting structural steel, before instituting any changes in what may be termed "temporarily established methods of manufacture and inspection."

For many years the writer has maintained, against bitter opposition, that Bessemer steel is not a fit material for the manufacture of bridges, notwithstanding which he was forced to accept it in the case of one important structure. This opposition to the Bessemer product is shown by the following extract from his latest specifications, which clause has appeared in a slightly different form in all of his superstructure specifications written during the last three or four years:

"All steel shall be manufactured by either the acid or the basic open-hearth process, preference being given to the former, and must be uniform in character for each specified kind. Any attempt to substitute Bessemer or any other steel for the open-hearth product will be considered as a violation of the contract, and a good and sufficient reason for canceling the same."

This clause has been criticized by contractors as being too peremptory and aggressive; but, so far as known, it has had the desired effect, for no attempt has apparently been made to substitute the Bessemer product on any of his work, although this may have been done without his knowledge, as he has often been informed that certain manufacturers make a practice of using metal inferior to that called for by the specifications or manufactured by a process prohibited therein. In this respect a chief engineer is at the mercy of his inspecting bureau

Mr. Waddell. if he employs one, and the managements of such bureaus too often relegate the inspection of important work to inexperienced and careless boys who pass anything and everything regardless of the instructions of the chief engineer.

The writer's limits for phosphorus have been 0.08% for acid steel, and 0.05% for basic, but it appears from the paper that he has been erring slightly on the wrong side, so it will probably behoove him to change. He did once specify 0.03% for basic steel, but it raised such a commotion among the bidders that he had to raise the limit to 0.05 per cent. It appears that the leading manufacturers of basic steel nearly always produce a metal containing less than 0.03% of phosphorus, but they object strenuously to being compelled to furnish it, on the plea that, in spite of all their efforts, an occasional output may contain as high as 0.05%, and they do not want the same to be rejected.

Since writing the clause just quoted from the specifications for the Northwestern Elevated Railroad, sufficient evidence has been presented to warrant the conclusion that basic open-hearth steel is fully as good and reliable as is the product of the acid open-hearth furnace. It seems though, that the use of the basic product tends toward the adoption of softer steel for bridge work. Whether this is advantageous or otherwise appears to be a mooted point. It has been the writer's custom to specify what he termed "medium steel" of an ultimate strength from 60 000 to 68 000 lbs. for all bridge members, excepting adjustable members, and rivets, for which he has used what he termed "soft steel," having an ultimate resistance between the limits of 53 000 and 61 000 lbs. The author would term these steels respectively "hard bridge steel" and "hard bridge rivet steel."

The writer would ask the author and other experts in structural steel whether, considering the latest developments in the manufacture of the basic open-hearth product, which he now recognizes as the coming metal for bridges, he is making a mistake in continuing to use so high a steel; and, if so, why and wherefore? Is there really an element of danger in employing such metal, or is the true reason for reducing the ultimate strength one of economy, caused either by a cheaper product or by the omission of reaming of rivet holes? If the last-mentioned cause be the only one, he will most decidedly make no change, because he maintains that in all the shops with which he is acquainted, the subpunching and the reaming of rivet holes are a necessity, if the holes are to match properly. If the cause be only a cheapening of the process of manufacture, it will be simply a question of economy as to whether to use a certain weight of medium steel at a certain pound price, or a greater weight of soft steel at a lower pound price. But if the question be one of safety or precaution, it cannot be ignored. In times past nobody appeared to object to using steel of an ultimate strength between 60 000 and 68 000 lbs., but such steel was manufac-

tured by the acid open-hearth process. In changing from acid to basic steel, he has not done so without consultation as to whether it is best to change also to soft steel, and thus far he has seen no reason for abandoning the medium steel used for a number of years. Mr. Waddell.

There are some other questions which he would like to ask the author, viz.: 1. What class of steel does he recommend for shop rivets for bridge work? 2. What class for field rivets for same? 3. In respect to reduction of ultimate strength for full-sized eye-bars, would he make the said reduction entirely a function of the thickness, or would he consider also the sectional area and perhaps also the length of the bar? The writer's practice has been to consider the area only, allowing a minimum strength of 60 000 lbs. for bars of 8 sq. ins. area and under, and 56 000 lbs. for those of 20 sq. ins. or over; bars with areas between these limits to have proportionate strength. The question is whether, for example, the limit should be the same for a bar 1½ x 4 ins. x 20 ft. as for one 1½ x 12 ins. x 40 ft. As far as his own practice is concerned, it does not matter much whether the function be one of thickness or one of area, because his limits of ratio of depth to thickness of bars are well restricted.

Some manufacturers have complained of the writer's limits for ultimate strength of full-size eye-bars as compared with those for test pieces of the material; but he finds that they can comply with both requirements by holding up the strength of test pieces for eye-bar metal towards the superior limit. Of course, it would be absurd to expect to obtain an ultimate strength of 60 000 lbs. for an eye-bar of 8 sq. ins. cross-section, if the strength of the metal used in its manufacture ran as low as 60 000 lbs. for small test bars.

In respect to elongation in 8 ins. for test pieces, it has been his custom of late to specify that the percentage shall not be less than 1 500 000, divided by the ultimate tensile strength. Using the higher limit of the latter, this method will give results agreeing very closely with the average minimum limits set in the paper. Similarly in respect to reduction of area, his custom lately has been to place the minimum limit at 3 000 000 divided by the ultimate strength. This also agrees fairly well with the average limits set in the paper.

It is undoubtedly more scientific to vary the elongation and reduction of area with the thickness of the metal and the shape of the section from which it was cut; and he is ready at any time to make the change in his specifications, provided that the consensus of opinion of those interested in the question be in favor of the change. It is unlikely that such a change can be made without considerable remonstrance from inspectors, on account of the extra trouble involved thereby to them. There should, however, be but little opposition developed on the part of the manufacturers, because the result of the change would be favorable to them rather than the contrary.

Mr. Webster. WILLIAM R. WEBSTER, Esq.—Justice cannot be done to the author's valuable paper in the short time available for discussion, but attention is drawn to the full series of papers on the physics of steel which was read at the International Engineering Congress, held in Chicago in August, 1893. This series will come up for discussion at the next meeting of the American Institute of Mining Engineers, and the writer hopes before that time to complete the tests and investigations on which to base a more searching criticism than that now presented.

Any one on reading the paper will be impressed with the great importance of putting into practical everyday use some good machine for testing material under shock; there are several impact machines in use for cast-iron, but not for steel, except those for drop tests of rails and axles. In 1879 Mr. William Kent suggested a good machine for tests of this kind, but the funds have never been found to build and run it.* Another promising machine is that of Mr. E. D. Estrada, which he described, with results obtained, in a paper before the Engineers' Society of Western Pennsylvania.†

If the author's remarks on the "tricks of the trade" are considered in connection with Dr. Charles B. Dudley's recent statements ‡ on the same subject, showing how it would be possible to vary the results of the tension test of pieces cut from the same plate or shape, and if they are used as a plea for a standard method of testing and wider limits to the specifications, they are all right; but to take them as they stand, the natural inference is that such methods are in daily use at the plate and shape mills, and that if such is the case, others may also be in use that have not been touched upon. This is not just to the mills or to the gentlemen who made these statements, as neither of them speak from actual experience.

Over 10 years ago, the chief engineer of one of our largest railroads in giving the writer instructions about his work, said:

"I want thorough tests and inspection made of the material and workmanship, and full reports made on same in order that we will, in the first place, secure good bridges, and, in the second place, that if one of our bridges should fail from derailed train or other cause, we could go before a jury and show by our test reports, etc., that we had put the best material in the structure, and used every precaution to guard against defective material or defective workmanship."

This made a great impression on the writer at the time, and to-day he considers it has even more force, owing to the general use of steel. Suppose one of these bridges should fail, with great loss of life; the case comes before a jury, and all test reports, etc., are produced; what weight will they have before that jury or any one else if such statements as Dr. Dudley's and the author's could be produced from the transactions of the leading engineering societies of the country and

* See the *Transactions* of the American Institute of Mining Engineers, Vol. VIII, p. 76.

† See the *Proceedings* of the Engineers' Society of Western Pennsylvania, June, 1893.

‡ See the *Transactions* of the American Institute of Mining Engineers, Vol. XXI, p. 391.

be shown to have been uncontradicted or not proved great exaggera- Mr. Webster.
tions?

The author, in his former paper * on "The Open-Hearth Process," referred to Bessemer and basic Bessemer steel as follows:

"In the field of structural work, as in other branches, the Bessemer converter is always a colossal rival. In the United States, Bessemer linings are almost universally acid, and, therefore, in the following detailed comparison of the two processes it will be unnecessary to consider the metallurgical position of the basic converter or the applicability of its products to the stringent demands of modern engineering."

In the present paper he refers to it as follows:

"It is acknowledged that the case is not yet closed, but until these statements are controverted by direct and positive evidence, the only safe way for the engineer is to prescribe that only open-hearth metal shall be used in all structures like railroad bridges, where the metal is under constant shock, and where life and death are in the balance. And it should be emphasized that if this provision is incorporated, a careful watch should be kept for fraud, as there is no way in which a substitute can be detected. The objections to Bessemer steel are many times emphasized in the production of the basic converter, for at the end of the operation there is often a very considerable percentage of phosphorus that passes back from slag to metal, and which is not always uniformly distributed. This fact utterly condemns it for the best of work."

We have on the other side of the question no less authority than C. Weyrich, Government Architect in Hamburg, Germany, whose paper on the subject will be found in the *Transactions* of this Society, Vol. XXX, page 219. His paper shows that basic Bessemer steel is not such a poor material after all, and that the author, without any experience whatever with the material, is a little premature in condemning it.

The paper states on page 312:

"It is a well-known fact that a mass of steel is never absolutely homogeneous owing to certain liquation phenomena known as segregation, and it is reasonable to suppose that this action will take place to a greater extent in a large mass of metal than in a small one. It is usually assumed that plates which have been rolled from ingots of a large size will show greater variations than those from more usual sections. Paradoxical as it may seem this is not always true, for in the preliminary roughing down or slabbing of the ingot, the top which is the most segregated portion is cut off as scrap. The upper third of the ingot will even than show some segregation in the interior, but Table No. 4 will show that it is of little practical importance."

In nearly all specifications for bridge work, a heat or flow of steel is made the unit, and it is the greatest importance to know just how much variation chemically, or physically, there is to be expected, and how to reduce the same to a minimum. Mr. Henry D. Hibbard

* See the *Transactions* of the American Institute of Mining Engineers, Vol. XXII, p. 349.

Mr. Webster. recently suggested before the American Institute of Mining Engineers the following precautions:

"To guard against segregation in ingots, the following precautions may be observed:

"*First.*—Cast ingots of the smallest practicable size.

"*Second.*—Cast ingots of as cold steel as practicable.

"*Third.*—Cast ingots as slowly as practicable.

"*Fourth.*—If the ingots must be large, and segregation is very objectionable, then purer stock than is otherwise needed must be used, or allowance made to cut off from the top or out of the center enough steel to remove the parts containing the worst segregation.

"*Fifth.*—The method above mentioned, of making what I have called incipient rising steel, must, it would seem, give ingots free from segregation. The steel in the mould is constantly in motion until the moment of solidification, and the impurities have no opportunity to collect anywhere. This method being applicable to soft steel only, however, will give no assistance in overcoming segregation in large high-quality hard-steel ingots."

At the same meeting Mr. Joseph Hartshorne said:

"After struggling with the problem of segregation for more than 15 years, I am in about the same state of mind as I was in the beginning. I do not yet know of any method of preventing it. It can be modified, and perhaps, minimized, by casting slowly, by using small ingots, by keeping the casting temperature as low as possible, etc.; but every now and then, in spite of all precautions, it will occur to a disastrous degree and can never be wholly prevented. The most homogeneous metal in appearance will show signs of it if carefully investigated. At least, I have never yet failed to find signs of this trouble, when I have looked for it carefully. I have been forced to the conclusion, therefore, that segregation cannot be prevented. In many instances it does not occur to an extent that makes much difference, and for many purposes it can be disregarded, but there is always the chance of the one time when it may take place with fatal results. The only solution yet presented of this problem, which is at all satisfactory to my mind, is that the impurities shall be kept so small in amount that segregation, if it does occur, will do no harm. In fact, I begin to fear that this will prove to be the final solution. Of course, I am speaking now of high-quality steel only.

"I agree with Mr. Hibbard in thinking that the hard spots which occur in steel may often be attributed to a local segregation. The usual explanation, that is, badly mixed or unmelted recarburizers, is inapplicable in so many cases that some other cause must be found. This one appears to me to be, at least, very plausible. I think it might be well to repeat here what I have before rather strenuously insisted upon, that the casting temperature of steel has a very decided effect upon the physical characteristics of the metal when cold, and that this effect is carried through to the finished product. Of course, I do not claim any originality for this remark, but it seems to me to be a point that is often overlooked, and it is one that has been denied."

In this same connection we have Mr. A. C. Cunningham's article on "An Instructive Eye-Bar Test," read before this Society March 21st, 1894, and published in Vol. XXXI of its *Transactions*. The writer would call attention to pages 416 and 417 of the article, to Mr. Robert's

discussion on page 418, Mr. Metcalf's on page 426, and Mr. Cunningham's reply on page 435, where this subject is also taken up. Mr. Webster.

But to the engineer it is of the greatest importance to know how the steel-maker decides on the proper amount to cut off the ingot, and also what use is made of the piece cut off. The writer's attention was called recently to an open-hearth steel boiler plate which failed in the shop, and upon an analysis being made the carbon was found to be about 100% higher at the point of fracture than in any other portion of the plate. When the steel-maker's attention was called to the matter he said that they "had not cut off enough from the top of the ingot." It is very fortunate that the plate failed in the shop and not in service.

In 1893 the Baldwin Locomotive Works issued specifications for steel boiler and fire-box plates, in which they only specified maximum limits of phosphorus for each grade of steel, leaving the other elements to the judgment of the steel-maker, but this did not give satisfactory results, and in January, 1895, they issued the following specification, which, as it has a carbon limit of 0.15 to 0.25%, is given here.

SPECIFICATION FOR STEEL BOILER AND FIRE-BOX PLATES.

"All plates must be rolled from steel manufactured by the open-hearth process, and must conform to the following chemical analysis, same being predicated on the use of Dr. Dudley's published methods of steel analyses:

	Boiler Steel.	Furnace Steel.
Carbon, between.....	0.15 and 0.25%.	0.15 and 0.25%.
Phosphorus, not over....	0.05%.	0.03%.
Manganese, not over.....	0.45%.	0.45%.
Silicon, not over.....	0.03%.	0.03%.
Sulphur, not over.....	0.05%.	0.035%.

"A careful examination will be made of every plate, and none will be accepted that show mechanical defects. Any accepted plate that develops defects in working will be rejected.

"A test piece from each plate rolled, taken lengthwise of the plate, and without annealing, should have an ultimate tensile strength of 60 000 lbs. per square inch, and an elongation of 25% in section originally 8 ins. long. The shape of test section to be as shown by sketch at beginning of this specification, all tests being made upon sections having, as near as practicable, ½ sq. in. of area.

"No plate will be accepted if its test piece shows an ultimate tensile strength of less than 55 000 lbs. or greater than 65 000 lbs. per square inch, or if the elongations fall below 20 per cent. The steel is to show the foregoing results when test machine is run at the rate of 1 in. in 3 minutes."

The following notes were sent to the writer by Mr. H. V. Wille, and explain the reasons leading to the adoption of the new specifications:

"Referring to carbon, Mr. Campbell states 'that no other element can confer a given increase in strength with as little diminution in ductility and as little increase in brittleness under shock. It is, there-

Mr. Webster.

fore, absurd to place any limit to the carbon content in a steel of given ultimate strength.' No one can take exception to the premises of this statement, but the conclusions are not at all warranted. All engineers recognize the value of carbon as a hardener, and do not regard it as an 'impurity,' as is evidenced by the fact that a minimum as well as a maximum limit is generally specified.

"For a long time we bought steel upon specifications limiting only phosphorus, and for reasons similar to those advanced by Mr. Campbell, but in the light of the experience gained during that time, we found it absolutely necessary to limit the carbon, for this is the only manner by which we can exercise a check on the heat treatment of a plate, guarding against it being rolled either too hot or too cold, in order to produce a certain specified tensile strength, and there are few mills that would hesitate to use either of these expedients should their preliminary tests prove them necessary.

"Mr. Henry M. Howe, in a paper on the "Heat Treatment of Steel," states that in soft steels the influence of carbon is at times completely masked by the effect of improper rolling; and one is safe in predicting that within the next few years we will witness a reaction against the present laxity in enforcing a carbon specification, and instead of making no provisions at all for this metalloid, specifications will be made more and more severe, perhaps based upon a sliding scale, making provisions for the presence of other elements, and for the gauge to which the steel is rolled.

"That these conclusions were not reached hastily, but after careful consideration of the whole problem, I quote a few tests bearing on this subject:

TABLE SHOWING EFFECTS OF COLD ROLLING.—A HALF-INCH SHEET.

	Section.	Tensile strength.	Elongation.	Analysis.
	Square inches			
Original test	2	57 255	37½	C., 0.13
Test made after rupture	2	58 130	33½	Mn., 0.46
Tests made after rupture, and sheet heated cherry red and allowed to cool	2	51 160	47 5/8	Phos., 0.044 Sul., 0 015 Si, 0.019

"We here have a sheet of cold rolled steel which failed at the first opportunity presented, notwithstanding that the adjoining sheet with 0.19 carbon had a tensile strength 10 000 lower.

"Test No. 131.41, in the accompanying table, cracked upon being bolted on the boiler, and was not heated in our works. A 0.30 carbon steel rolled to ½-in. plate should pull higher than 59 000 lbs. Insufficient work was probably put upon this plate, and it was finished at too high a temperature; and I finally quote in the same table in plate No. E 412, a test showing a bad case of segregation. It is well known that all the metalloids, including carbon, are apt to segregate in the top of the ingot. By limiting the carbon we compel the mills to discard, in a measure, a certain percentage of their ingots, for they cannot tell from what part of the plate we are liable to take drillings, and any failure of steel not only entails considerable expense to the mill, but also tends to throw some discredit on their product."

TABLE SHOWING EFFECTS OF INSUFFICIENT WORK AND OF SEGREGATION. Mr. Webster.

Test No.	Ultimate strength. Pounds per square inch.	Elongation in 8 ins. Percentage.	Analysis				Remarks.
			C.	Mn.	P.	S.	
131.41.....	59 100	29.12	0 30	0.46	0.009	0.022	Drillings from crack.
"	61 020	28.75	0.32	0.37	0.009	0.022	" " sheet.
E. 412.....	52 610	25.25	0.18	0.44	0.017	0.014	Original.
"	64 210	16.62	.....	.....	.....	.....	Olsen.
"	54 940	28.75	.....	.....	.....	.....	Mill.
"	65 450	5.00	.....	.....	.....	.....	Punched from plate.
"	61 080	4.12	0.33	0.50	0.056	0.033	Drilled from plate.

The writer considers the author's high limit of .10% for sulphur in Classes V, VI, VII, VIII, IX, and X entirely too high, and especially so for the eye-bar material in Classes V, VI, VII, and VIII, and other forgings in Classes IX and X. The eye-bars are the most important forgings in a bridge, and it would be the worst kind of policy to put material in them containing twice as much sulphur as would be considered safe to allow in rivets in Classes II, III, and IV. It is not clear from the author's specifications just what tests are to be made on eye-bar material at the mill; his full-size tests are very complete, but we need some better system of testing the material at the mill than that now in use, for it is not an uncommon thing to have an eye-bar break in full-size test in the body of the bar away from the portion heated in making the heads, with little or no reduction of area and poor stretch. Failures of this kind have occurred in open-hearth steel as well as Bessemer steel. The steel-maker claims that his material is all right, but that it was spoiled in the annealing, while the manufacturer, on the other hand, claims that his method of working is all right. The analysis, in some cases, will not show the cause of the trouble. It is, no doubt, due in some cases to the bars being rolled on a light mill and finished at too high a temperature. This trouble not always being removed by the ordinary annealing, the writer would strongly advocate more rigid requirements and tests for the eye-bar material than have yet been proposed. He does not agree with the author in any of the following recommendations, to "use a small test ingot rolled into test bar to save expenses of cutting test bar from forgings, or to use similar tests for castings, and to use castings of simple form without annealing." All castings should be annealed and tests made on all materials as used and not in an improved condition due to rolling or forging to smaller size. The matter of expense does not enter into the case, as it can be provided for when the contract is taken. The Baldwin Locomotive Works have been through this matter, and their experience may be of interest. The following is from the writer's remarks in the discussion on "The Physics of Steel" before the American Institute of Mining Engineers:

Mr. Webster. "The experiments of Mr. Howe on the heat treatment of steel are of the greatest value, and throw much light on the changes which occur in the structure of the metal. I trust that such experiments will be continued on a larger scale, in connection with the work of rolling or forging at different temperatures. A test report received from Mr. S. M. Vauclain, superintendent of the Baldwin Locomotive Works, gives the result of tests made upon two 8½-in. steel blooms, furnished to the works to be forged into axles. They had been bought on a specification calling for a certain tensile strength and elongation in a test specimen cut from the blooms and drawn down under the hammer to 1 in. square. Some large driving axles, forged from such blooms, having failed to meet the physical requirements of the purchaser, although the test specimens had met the requirements of the specification, and although such failure had never been experienced before, even with forgings from 6½-in. blooms, it was suggested that the cause of the failure might be that the particular blooms from which the axle had been forged had received little or no work in the mill; in other words, had been rolled from small ingots instead of large ones. In order to ascertain the effect of extra working, two sample blooms were forged from 8½ down to 7, 6, 5 and 4 ins. successively, and test specimens were taken at each stage. It was found that the successive forgings materially enhanced the value of the steel. The elongations increased as the size was diminished by forging. It was noticed, however, that in the first bloom there was a slight decrease, and in the second a considerable increase of tensile strength. This phenomenon is attributed by Mr. Vauclain to the circumstance that the second bloom had been allowed to retain its original size at the bottom of the ingot. On the result of this experiment, Messrs. Burnham, Williams & Company, of the Baldwin Locomotive Works, changed their specifications so as to require that the test-piece should be cut from the bloom furnished.

"The small elongation and crystalline fractures of the larger sizes covered by this report show clearly, I think, the trouble caused by improper heat treatment, while the greatly superior results in the smaller sizes indicate the true value of the material. By annealing the larger pieces, the stretch and fracture might be made, no doubt, equal to those of the smaller pieces in their present state, but it is only by careful experiment that the best methods of working can be established."

The results given by the author, in Table No. 13, showing the influence upon the elongation of a change of length of the test-piece, and in Table No. 14, on other physical properties are misleading, as the pulling speed of the machine was the same in all cases, which gives pulling speed on a 2-in. piece, and a 14-in. piece as 7 to 1; therefore, the results are not due to difference in lengths alone, but partially to difference in pulling speeds, as shown by Table No. 17. The ordinary allowance in plate-mill testing is 5% increase in tensile strength in 2-in. boiler test over the ordinary 8-in. test, the pulling speed of the machine being the same, that is, the 2-in. piece being pulled four times as fast as the 8-in. piece.

The author's conclusions, as regards universal plates, are based on tests made on material cut from the edges of the plates. Such pieces

Mr. Webster.

give lower ultimate strength, lower elastic limit, with more reduction and more stretch than pieces cut from the center of plates; the cross-bends of universal plates are not as good as the longitudinal bends. Before accepting his additional requirements for material of this kind above those for sheared plates, we should have a very complete series of tests covering the points raised, and then if the requirements are accepted, limit the width, so covered, to 36 ins. and under, as there is only one mill in the country than can roll universal bridge plates up to 42 ins. in width.

The writer considers the elastic limits and elastic ratios given in the paper too high and very misleading. The author appreciates this, no doubt, for after giving in his tables elastic ratios of 72.9, 70, 73, etc., on material ⅜ in. thick, as though they were of every-day occurrence, in his specification he has only two cases in which he calls for 60% elastic ratio in plates ⅜ in. thick, and four in which 60% is called for in angles ⅜ in. thick, and in no case is 60% called for in material over ½ in. thick. But assuming that these specifications are all right as to elastic limits specified, then what practical value is there in asking for angles with 63% elastic ratio, and making a chord section by riveting these angles to plates with only 49% elastic ratio? The strength of the member would depend on the 49% elastic ratio, which is very close to the old idea of "elastic limit of not less than one-half the ultimate strength."

Assuming on the other hand that the elastic limits and elastic ratios as given in the tables are all right, and not questioning the author's results or methods of testing, the writer endeavors to find out what they show, and whether the author's conclusions are justified in any way by the results as given in these tables.

Table No. 8 shows that the elastic ratio of Bessemer steel is 3.04% higher than that of basic open-hearth steel of same ultimate strength as given below:

Bessemer.		Open-Hearth.	Difference.	Bessemer.		Open-Hearth.	Difference.
Rounds.....	71.88	68.81	3.07	Flats.....	71.33	69.51	1.82
"	73.00	68.51	4.49	"	70.92	68.36	2.56
"	71.34	69.47	1.87	"	70.31	64.96	5.36
"	69.42	66.71	2.71	"	67.93	65.50	2.43
Average difference.....			3.04	Average difference.....			3.04

Table No. 11 shows that the elastic ratio of Bessemer steel is 3.52% higher than that of acid open-hearth steel with same phosphorus content, and 4.10% higher than acid open-hearth steel with

Mr. Webster. from 0.02% to 0.03% lower phosphorus content, the materials compared having same ultimate strengths in each group as given below:

Ultimate strength Pounds per square inch.	Thickness of angles in inches.	Acid Bessemer. P. 0.07 to 0.10.	Acid open-hearth. P 0.0 to 0.10.	Difference.	Acid open hearth. P. 0.05 to 0.07.	Difference.
56 000 to 64 000.....	$\frac{5}{16}$ to $\frac{3}{8}$	71.58	68.50	3.08	67.72	3.86
	$\frac{7}{16}$ to $\frac{1}{2}$	71.00	66.30	4.70	65.66	5.34
	$\frac{9}{16}$ to $\frac{5}{8}$	69.11	64.96	4.15	64.50	4.61
	$\frac{11}{16}$ to $\frac{3}{4}$	66.70	64.15	2.55	63.63	3.07
64 000 to 72 000.....	$\frac{5}{16}$ to $\frac{3}{8}$	70.09	67.02	3.07	66.15	3.94
	$\frac{7}{16}$ to $\frac{1}{2}$	68.66	65.06	3 60	64.87	3.79
Average difference ...	.....	.....	.....	3 52	.....	4.10

Table No. 16 gives the following differences in the elastic ratio in sheared plates corresponding to different widths of test pieces.

Test piece $\frac{1}{2}$ in. wide has 65.58% elastic ratio.
" $\frac{3}{4}$ " " 63.00 " "
" 1 " " 62.29 " "
" $1\frac{1}{2}$ " " 62.11 " "
" 2 " " 62.18 " "

Now, in order to keep the area of the test pieces down to $\frac{1}{2}$ sq. in., the following widths would have to be used for test pieces cut from plates $\frac{5}{16}$ in. to $1\frac{1}{4}$ in. thick. The differences in elastic ratio due to these widths of test pieces are given below.

Thickness.	Width.	Elastic ratio from above.
$\frac{5}{16}$ in.	1.59 in.	62%
$\frac{3}{8}$ "	1.33 "	62%
$\frac{1}{2}$ "	1.00 "	62%
$\frac{3}{4}$ "	0.66 "	63%
$1\frac{1}{4}$ "	0.40 "	66%

That is an increase of 4% in the elastic ratio for the $1\frac{1}{4}$-in. plate, but the allowance in the different classes of material, V, VI, VII, VIII, IX, XI and XII, is a decrease of 9%, or just the other way. Is this in spite of the difference due to narrow test piece? If such is the case, the proper allowance for test pieces $1\frac{1}{2}$ ins. wide would be 13% between $\frac{5}{16}$-in. plates and those $1\frac{1}{4}$ ins. thick.

Table No. 17 gives the following differences in ultimate strength, elastic limits and elastic ratios due to differences in pulling speed. From this table it will be noticed that there is a difference in ultimate strength of 2 048 lbs., a difference in elastic limit of 6 061, and a difference in elastic ratio of 7.51 per cent. This would have been much

more complete had the author stated which of these results he considered the true elastic limit. Mr. Webster.

In ordinary testing, different combinations of the above speeds are used as follows:

Pulling speed. Inches per minute.	Ultimate strength. Pounds per square inch.	Pulling speed. Inches per minute.	Elastic limit.	Elastic ratio.
4.50	61 075	0.07	39 647	64.9
4.50	61 075	0.38	41 763	68.2
4.50	61 075	0.67	42 904	70.2
4.50	61 075	3.00	44 410	72.7

That is, with the same ultimate strength a difference of 4 768 lbs. can be obtained in the elastic limit and 7.8% in the elastic ratio, by using different pulling speeds. Applying these results to Bessemer and open-hearth steel plates under the following conditions, we get rather surprising figures.

Bessemer plate.	Open-hearth plate.	Increase in the elastic ratio of Bessemer plate.	
Thickness ¾ in.	1½ ins.	Due to thickness	+ 9.00%
Phos. 0.07 to 0.10	0.05 to 0.07	Due to method of manufacture and higher phos.	+ 4.10%
Fast speed	Slow speed.	Due to pulling speed	+ 7.80%
Width, 1½ ins.	1½ ins.	Due to width of test piece	+ 0.00%
Total increase			+ 20.90%

This difference of 20.9% in the elastic ratio of a 60 000-lb. steel equals a difference of 12 540 lbs. in the elastic limit of the material. These results are very instructive and will show the engineers who are asking for very high elastic limits that it is an easy matter to give them almost anything they want by using this "go-as-you-please" method of testing and by not checking the elastic limit as given by the drop of the beam, by using dividers on test piece, or any other method of check.

Taking another case of where high results are wanted on the plate 1¼ ins. thick:

Bessemer plate.	Open-hearth plate.	Increase or decrease in the elastic ratio of Bessemer plate.	
Thickness, 1¼ ins.	¾ in.	Decrease due to thickness	—9.00%
Phosphorus, 0.07 to 0.10	0.07 to 0.10	Increase due to method of manufacture.	+3.52
Fast speed.	Slow speed.	Increase due to pulling speed	+7.80
Width, 40 ins.	1.50 ins.	Increase due to the width of test piece	+4.00
		Total increase	+6.32

Mr. Webster. This difference of 6.32% in the elastic ratio of a 60 000-lb. steel equals a difference of 3 792 lbs. in the elastic limit; that is, the 1¼-in. plate, even after the author's allowance of 9% in elastic ratio, gives about 4 000 lbs. higher elastic limit than the ⅜-in. plate. If the allowance of 9% on account of thickness is not made on the 1¼-in. plate, then there is 15.32% higher elastic ratio, or about 10 400 lbs. higher elastic limit than the ⅜-in. plate, which does not agree with the usual results in every-day work.

Last August the writer stated to the superintendent of the X Steel Works that the elastic limit of 38 000 lbs. called for in Mr. George H. Thomson's new specifications was too high for an ultimate strength of 58 000 to 65 000 lbs., with 26% stretch in 8 ins. He claimed that he could get it without any trouble. The writer offered to make a complete series of tests on the 200 000-lb. Olsen machine, at the Pottstown Iron Company's works, to decide if the high elastic limit was due to material or the method of testing. The offer was accepted, and a large number of tests were made of material manufactured by the X Steel Works. The results were as follows:

About 60 tests were made at Pottstown in the ordinary manner, taking the elastic limit by the drop of the beam, and checking the same by the use of dividers on the test piece. The machine has an electric automatic device for running out the poise, the weighing beam making and breaking the circuit. These results and those of X Steel Works on the same material were as follows:

Shape.	Ultimate strength. Pounds per square inch.		Elastic limit. Pounds per square inch.		Elastic ratio. Per cent.		Elongation in 8 ins. Per cent.		Reduction of area. Per cent.	
	X Works.	Webster.	X Works.	Webster.	X Works.	Webster.	X Works.	Webster.	X Works.	Webster.
Rounds.										
Bessemer	63 249	60 890	46 086	34 951	72.9	57.4	26.81	26.84	53.8	63.9
Open-hearth..	61 621	61 050	42 523	33 169	69.0	54.3	28.38	28.55	61.3	67.5
Angles.										
Bessemer	58 889	58 180	42 362	35 943	71.9	61.8	28.73	28.78	56.2	60.1
Open-hearth..	60 258	60 288	39 053	33 488	64.8	58.9	29.98	31.20	58.4	58.9

These results were a surprise to both experimenters, but the only difference to be found by correspondence in the methods of taking the elastic limits was that at the X Steel Works they had no automatic arrangement to operate the poise, and ran it out by hand. This brings in to a greater extent the personal equation of the operator than where the automatic arrangement is used, for he not only has to watch for the drop of the beam, but at same time must run out the poise.

Mr. Webster.

In order to compare the elastic limit as taken by the drop of the beam, under different conditions of pulling and poise speeds, and at the same time to check these results with the elastic limits taken by Mr. Olsen's autographic device, the following tests were made by Mr. E. A. Custer, of the Baldwin Locomotive Works, on an open-hearth round $\frac{7}{8}$-in. steel bar. The results tabulated are the averages of sets of three tests each :

	Pulling speed, 1 in. in 3 minutes. Speed of poise, 53 000 lbs. in 1 minute.*	Pulling speed, 1 in. in 3 minutes. Speed of poise, 19 840 lbs. in 1 minute.†	Pulling speed, 4 ins. in 1 minute. Speed of poise, 53 000 lbs. in 1 minute.†
Ultimate strength.....	57 340 lbs. per square inch.	56 300 lbs. per square inch.	58 870 lbs. per square inch.
Elastic limit :			
Autographic device..	35 990 lbs. per square inch.	36 250 lbs. per square inch.	35 890 lbs. per square inch.
Elastic ratio.....	62.8%.	64.4%.	60.9%.
Elastic limit :			
Drop of beam.....	37 300 lbs. per square inch.	37 720 lbs. per square inch.	40 530 lbs. per square inch.
Elastic ratio.....	65.1%.	67.0%.	68.8%.
Reduction of area.....	59.9%.	58.6%.	61.1%.

The greatest difference in the elastic limits as taken by the drop of the beam is 3 230 lbs. between first and third cases ; this is equal to a difference of 3.7% in the elastic ratio. The greatest difference in the elastic limits, as taken by the autographic device, is only 360 lbs. between the second and third cases, but the difference in the elastic ratio is 3.5%, owing to difference of 2 570 lbs. in ultimate strength due to difference in pulling speeds. The greatest difference in elastic limits, as taken by the autographic device, and those taken by the drop of the beam, is 4 640 lbs. in the third case ; this is equal to a difference of 7.9% in the elastic ratio.

As all of these tests were made on pieces cut from the same bar, the differences in results are due to the systems of testing used in each case; these differences would have been greater, no doubt, if there had been another set of tests made by running the poise out by hand.

The writer is also indebted to Mr. Custer for the diagram (Fig. 1) taken by the autographic device, on which he has noted the beam readings as taken by the drop of the beam. The beam readings are represented by ordinates and the elongation by abscissas. There is a well-defined break in the lines for speeds of 1 in. in 15 minutes, with very slight differences between readings by drop of beam and diagram. But in the case of a speed of 4 ins. per minute the line is very different and the bend much more gradual, with a difference in readings by drop

* Speed of poise greater than rate of applying weight.

† Speed of poise slower than rate of applying weight.

Mr. Webster. of beam and diagram of 3 730 lbs. These results were also sent to the superintendent of the X Steel Works, but he wanted further light on the cause of the discrepancy in them and sent six sets of six pieces, each of 2 x $\frac{3}{8}$-in. bars, to different mills and manufacturers to be tested.

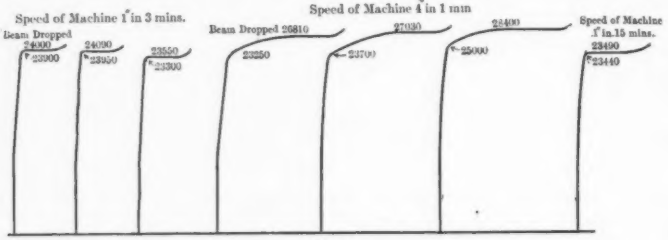

FIG. 1.

The pieces sent to one party were too short for their machine, and Messrs. Riehlé Brothers tested these. The average result of each set of six bars was as follows :

	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Percentage of elongation in 8 ins.	Percentage of reduction of area in 8 ins.
X Steel Works.....	61 220	42 295	69.1	29.58	61.60
Webster.....	61 233	38 703	63.2	30.46	59.00
A	62 037	41 495	66.9	31.46	61.00
Baldwin.....	60 795	38 679	63.5	29.50	56.50
B.....	61 275	40 138	65.5	30.71	53.80
C.....	62 303	41 345	66.4	29.79	60.70
Riehlé Brothers.....	60 590	38 659 to 29 496	63.6 to 65.4	32.30	53.50

The greatest difference in the averages of the elastic limits of original observers is 3 716 lbs. between the first and fourth lines; this equals a difference of 5.6% in the elastic ratio. But the greatest difference in the elastic ratio is 5.9% between the first and second lines; this is due to the ultimate strength being higher in the second line than in the fourth, and giving a lower elastic ratio, although the elastic limit is slightly higher than in the fourth line.

The writer endeavored to get another set of these test pieces from the X Steel Works in order to have the elastic limit taken by the extension of the test pieces using the extensometer. They reported that they had none of the material left, but sent 10 pieces of $\frac{3}{4}$-in. rounds from steel that had been thoroughly tested. Mr. Custer tested five of these pieces, and Messrs. Riehlé Brothers the other five. The results were as follows :

	X Steel Works. Average of 25 tests	Mr. Custer.		Riehlé Brothers.	
		Average of 5 tests.	Average of 5 tests.	Average of * 5 tests.	
Ultimate strength.					
Pounds per square inch.	60 123	60 036	.....	61 655	
Elastic limit.					
Pounds per square inch.	43 159	41 409	39 582	39 988	40 777
Elastic ratio, per cent....	71.8	69.0	65.9	64.8	66 1
Method.....	.....	Drop of beam.	Autographic device.	Average of 4 tests; extensometer and electric contact.	1 test by drop of beam.
Elongation in 8 ins.					
Per cent.....	30.16	30.75	.....	28.93	
Reduction of area.					
Per cent.....	66.80	67.78			

*The figures for elastic limit in this column are for four tests only.

Tests of Mild Steel Plate Pieces, Measuring 2 x ⅝ Ins.

Load per Square Inch.	10 027		10 028		10 030		10 065		10 066	
	Reading.	Stretch per 1 000 lbs.	Reading.	Stretch per 1 000 lbs.	Reading.	Stretch per 1 000 lbs.	Reading.	Stretch per 1 000 lbs.	Reading.	Stretch per 1 000 lbs.
25 000..	.0042	.000168	.0062	.000248	.0016	....	.0084	.000336	.0038	.000152
26 000..	.0044	.0002	.0064	.0002	.0018	.0002	.0086	.0002	.0040	.0002
27 000..	.0047	.0003	.0068	.0004	.0020	.0002	.0088	.0002	.0042	.0002
28 000..	.0049	.0002	.0071	.0003	.0021	.0001	.0090	.0002	.0044	.0002
29 000..	.0050	.0001	.0073	.0002	.0022	.0001	.0092	.0002	.0046	.0002
30 000..	.0052	.0002	.0075	.0002	.0023	.0001	.0096	.0004	.0047	.0001
31 000..	.0056	.0004	.0079	.0004	.0025	.0002	.0098	.0002	.0049	.0002
32 000..	.0058	.0002	.0081	.0002	.0027	.0002	.0100	.0002	.0050	.0001
33 000..	.0060	.0002	.0084	.0003	.0029	.0002	.0101	.0001	.0052	.0002
34 000..	.0062	.0002	.0087	.0003	.0030	.0001	.0102	.0001	.0054	.0002
35 000..	.0064	.0002	.0090	.0003	.0031	.0001	.0103	.0001	.0057	.0003
36 000..	.0066	.0002	.0092	.0002	.0033	.0002	.0105	.0002	.0060	.0003
37 000..	.0068	.0002	.0095	.0003	.0037	.0004	.0108	.0003	.0062	.0002
38 000	.1838	.1770	.0098	.0003	.0039	.0002	.0170	.0062	.0064	.0002
39 000..	.2039	.0201	.0100	.0002	.0040	.0001	.0510	.0340	.0068	.0004
40 000..	.2148	.0109	.0426	.0326	.0041	.0001	.0740	.0230	.0088	.0020
41 000..	.2278	0130	.1720	.1294	.0210	.0169	.2026	.1286	.0104	.0016
42 000..	.2490	.0212	.2055	.0335	.0780	.0570	.2180	.0254	.1950	.1846
43 000..	.2705	.0215	.2222	.0167	.0838	.0058	.2344	.0164	.2068	.0118
44 000..	.2790	.0235	.2416	.0194	.1087	.0249	.2542	.0198	.2202	.0134
45 000..	.2705	.....	.2606	.0190	.2235	.1148	.2788	.0246	.2390	.0188
46 000..	.2940	.....	.2820	.0214	.2410	.0175	.2948	.0160	.2552	.0162
47 000..	.....	.....	about .3080	.....	.2594	.0184	about .3200	.....	.2758	.0206
48 000..	.....	.....	.....	.....	.....	.....	.....	.....	.2972	.0214

	10 027	10 028	10 030	10 065	10 066
Elastic limit.....	38 000	40 000	41 000	38 000	40 000
Maximum load.....	57 460	60 840	62 960	60 490	62 290
Elongation. Per cent.....	33.1	31.0	33.0	32.3	32.5
Reduction in area. Per cent.	52.1	54.6	48.85	53.33	56.24
Fracture.....	45° Silky.	Cup. Silky.	Silky. 45°.	Silky. Cup and 45°.	Silky. Cup and 45°.

Mr. Webster.

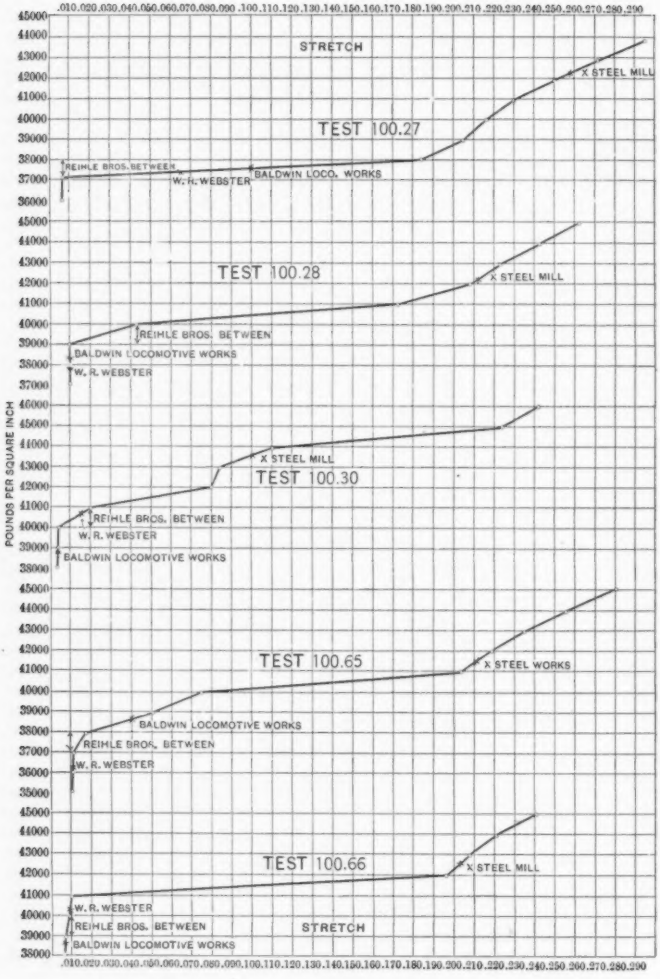

FIG. 2.

Mr. Webster.

After this Messrs. Riehlé Brothers made a complete set of tests on one of the original sets of 2 x ¾-in. test pieces, taking the extensions for each increase in load of 1 000 lbs. per square inch from 30 000 to 44 000 lbs. Their results are given in full, with diagrams of the extensions (Fig. 2). The writer is under obligations to Mr. Wille for a full analysis of the broken test pieces as well as for the diagrams (Fig. 2).

The tests summarized in the second table on page 375 were made with a Riehlé-Buzby extensometer, which was set at zero for a zero load. The readings represent actual extensions for each increase of 1 000 lbs. per square inch in the loading. The first load to about 24 000 lbs. per square inch was applied with a head-fall of 1 in. in 64 seconds. From that point to beyond the limit, at $\frac{1}{16}$ in. per minute, and then at 0.2 in. per minute, until the test piece showed a slight reduction at the breaking point. From that point to the break, a head-fall of 0.4 in. per minute was used. In a letter accompanying the above table, Messrs. Riehlé Brothers state:

"Please note that the elastic limits shown are for the first 1 000 lbs. per square inch above the limit. In the absence of any definite instructions on this point we simply took the first reading showing disproportionate stretch; hence all these quantities should be more or less minus. In the case of No. 10 027, the limit was probably about 37 200 lbs. per square inch, while in No. 10 028 it was probably 39 800 lbs. per square inch, as indicated by the amount of extension."

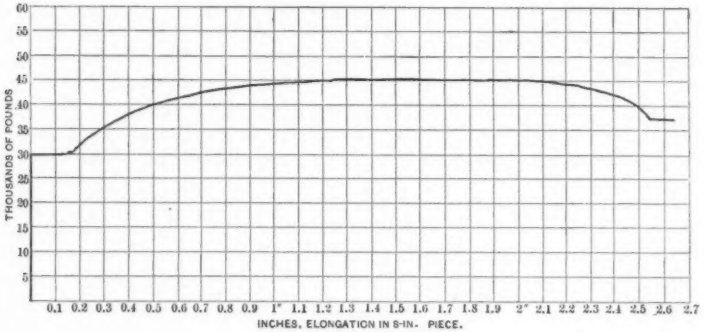

FIG. 3.

A sixth piece was tested autographically and the diagram (Fig. 3) is reproduced from the chart made by the machine, which has an automatically balanced beam. The vibration of this beam closes a circuit which operates a clutch propelling the poise. The elastic limit of this piece was 39 957 lbs. per square inch; the maximum load, 59 550 lbs. per square inch; the elongation in 8 ins., 32.1%; the reduction in area, 54.4%, and the fracture 45° and silky.

Mr. Webster. The following letter was sent to the writer by Mr. Wille at the same time the strain diagrams (Fig. 2) were transmitted:

"I send you herewith stress-strain curves plotted from the results of tests made by Riehlé Brothers on samples of steel furnished by the X Steel Mills. These tests show that immediately after the elastic limit is passed the piece yields rapidly and then recovers quickly after which each augmentation of stress results in an approximately proportional increment of strain until the maximum stress is reached. This rapid yielding, recovery and subsequent stretching gives a drop of the beam at two distinct points on the stress-strain curve. The first drop is sometimes scarcely perceptible, the second usually very decided. You will notice that the X Steel Mills almost invariably take their elastic limit after the specimen has recovered from its greatest increment of stretch. I have marked the point recorded as the elastic limit by the different observers by a cross.

"It will be noticed that with one exception the X Steel Mills have recorded their elastic limits when the pieces had stretched 0.2 in. From this it would appear that they waited until the beam settled well down on the second fall. An inspection of the curves shows that ordinarily no error of serious magnitude would be made if the elastic limit be taken when the specimen has elongated as much as 0.1 in., considering soft steels only, and it would not be very difficult for an observer to catch the stress upon the piece under this strain either by the simple fall of the beam or by checking up with a pair of dividers, as the United States Testing Board did in its original tests.

"I also attach the analyses of these samples. In all cases duplicate determinations were made and some of the elements were determined by entirely different methods. The sulphur was determined by evolution, and perhaps on account of the high percentage of copper present, the results may be low. The carbon was determined by color comparison being made against a Carnegie 0.217 carbon open-hearth steel"

ANALYSES OF 2 x ⅝-IN. STEEL BARS.

	10 027.		10 028.		10 030.		10 065.		10 066.		10 072.	
			First determination.	Second determination.	First determination.	Second determination.	First determination.	Second determination.	First determination.	Second determination.	First determination.	Second determination.
Carbon	.19		.18	....	.18	....	.18	....	.20	....	.18	
Manganese	.44	.45	.43	.47	.50	.53	.50	.52	.52	.49	.45	.47
Phosphorus	.078	.078	.091	.088	.092	.088	.071	.070	.076	.077	.074	.074
Sulphur	.025	.027	.038	.041	.035	.036	.039	.040	.035	.037	.032	.034
Copper	.13	....	.097	....	.086	....	.131	....	.10	....	.12	
Silicon	.002	....	.005	....	.005	....	.003	....	.003	....	.003	

The author claims a decrease of 6% in the reduction of area and 3% in the elongation when the thickness of plate is increased from ¾ in. to 1¼ ins.; this may agree with the results of the two mills he refers to, but others get different results. The writer has a table compiled from

several hundred tests of one of our largest mills, and it shows an increase of 6% in the reduction of area and 1% in elongation in going from ½ in. thickness to 1¼ ins. This would indicate that the differences observed are not due to the thickness of the material, but they may be accounted for by different methods of rolling, and different finishing temperatures in rolling. Too much importance cannot be given to this important branch of the manufacture of structural steel. Mr. Webster.

During the past four years, the writer has made a very exhaustive series of tests in order to find out the relations between the "chemical constitution of steel and its physical properties," and in the course of the work soon found out that the true starting point of the investigation was the heat treatment of the steel. The following is from his papers giving results of this work :*

"In all rolling-mill work it is generally conceded that the temperature at which the material leaves the rolls is an important element, as affecting the ultimate strength and stretch of the finished product. This is a hard matter to control, and the difficulty is greatly increased with long, wide or extremely thin plates, all of which would naturally be finished a little colder, and would therefore give higher ultimate strengths, while the chances are that very thick plates will be finished too hot. On tonnage-work it is not easy to hold material back in rolling; and the temperature in finishing is controlled in various ways at different mills, with more or less success. But the difficulty is not recognized at all by the engineers in their specifications, which ask for the same results in all widths.

"Most of the specifications for steel assume that the ultimate strength and the relation between it and the stretch of a given grade of steel will be the same under all conditions, whether it be rolled into shapes, universal plates, or wide sheared plates. The ultimate strength under these conditions is only allowed to have a variation of 8 000 lbs., and in some cases very much less. The manufacturers have themselves principally to blame for this state of affairs, since engineers are only asking for results corresponding to test reports shown them by the manufacturers as representing what they could do, which, however, usually are not average results. As the differences due to the method of rolling, as well as the section of the finished product, are recognized in specifications for iron, they should also be recognized in those for steel.

"The relief most needed to-day is the adoption of one uniform specification and standard-size test piece, the method of testing being provided, and limits left broad enough to cover the variations referred to above. Proper allowance should be made for both ultimate strength and stretch in extremes of thickness, width or length."

The other points brought out in this investigation are that reliable results cannot be had with narrow test pieces cut from thick plates, and that heavy reductions in rolling which are sufficient to bring out the "second heat," as the rollers termed it, injure the material, no matter what the final finishing temperature may be. More tests are needed on this subject and close attention must be paid to heating of the blooms, reductions in rolling and finishing temperature.

* See the *Transactions* of the American Institute of Mining Engineers, Vol. XXI, p. 766.

Mr. Webster. The writer considers that many of the so-called mysterious failures referred to in the paper may be accounted for by improper heat treatment of the material. The author claims that most of them are due to phosphorus, and in this, no doubt, is right, yet in some cases the chemical analysis shows the material to be all right. It is in these cases that we should look up the heat treatment of the material before falling back on the gases to account for the trouble.

The writer is more firmly convinced than ever that the true starting point in any investigation of this kind is the heat treatment of the material, and back of that, of course, thermo-chemistry. In this connection the remarks of Mr. H. M. Howe on the "Pyrometry and Heat-Treatment of Steel" will be of interest.*

Mr. Howe. HENRY M. HOWE, Esq.—The author's words: "There is good testimony to show that the product of the converter is an inferior metal, which gives way in a treacherous manner under shock," seem to the writer unsupported by the evidence quoted, and inconsistent with the extensive use of Bessemer steel in Europe for bridge material. The words suggest, perhaps unintentionally, that inferiority and treachery are both unavoidable and habitual, which is a grave mistake. The author objects even more to basic Bessemer steel, because after its phosphorus has been removed, it may take it up again from the slag when the recarburizing reaction occurs. It is possible that he overlooks the recent advances which have been made in basic Bessemer procedure, by which the recarburizing occurs when only very little slag is in contact with the metal. Under these conditions, it is stated on credible authority, practically no phosphorus is taken up by the steel. Particular reference is here made to the Darby method of recarburization. In this, the slag is poured off as fully as possible; the remaining slag is then thickened by adding lime to it, so that it becomes so stiff as to tend to dam itself back; the metal is then poured out from beneath the slag, and as it runs a stream of fine coke or charcoal is shot into it, to recarburize it. Under these conditions it is hard to suppose that much rephosphorization can occur.

Many people whose opinions deserve weight have a strong prejudice against Bessemer steel. On the other hand, many others have the highest opinion of it; and, what is far more important, it is used extensively for objects, such as bridges and boilers, for which treachery would certainly unfit it. This is more particularly true of continental Europe.

This state of things can best be explained by the obvious supposition that if, in making Bessemer steel, certain classes of pig iron, viz., those too rich in silicon, be used, and if certain objectionable methods of manufacture be followed, treachery may result; but if proper mate-

*See the Presidential address before the American Institute of Mining Engineers. February, 1894.

rials, methods of manufacture, and inspection are used, such treachery can be absolutely prevented. It seems that any other explanation is excluded by the facts before us. Were this the proper place, abundant evidence could be given in support of the apparent trustworthiness of Bessemer steel, even of basic Bessemer steel. Mention may be made to a few striking instances, taken from an important work* by Professor Tetmajer, who has lately and very thoroughly examined the trustworthiness of basic Bessemer steel, and whose conclusions tally ill with the picture which the author draws. Indeed, it is surprising that he should have spoken as he does in view of Professor Tetmajer's results. The latter says that the use of basic Bessemer steel for railroad bridges is officially permitted by the English, French, Italian, German and Swiss railroads; that in some German basic Bessemer works with an annual production of from 12 000 to 15 000 blows, often a whole year will pass without a single blow which is cold short from phosphorus; and that, of 27 044 basic Bessemer rails on the Swiss Northeastern Railroad, only two broke between 1885 and 1893. Of these, 5 045 had been in use for eight years, 7 934 for seven years, 6 291 for six, and 7 774 for five years. Mr. Howe.

In summing up, Professor Tetmajer says:

"By the usual deoxidizing and recarburizing methods one can make in the basic converter rail steel which, as regards uniformity of composition and the absolute quantity of the non-ferrous elements (*assesorische Beimengungen*), is fully equal to the product of the acid process. By the use of Darby's recarburizing process one can make a pure carbon steel of any desired hardness with a degree of certainty which hitherto has neither been wished nor reached in rail-making" (even by the acid open-hearth process).

The author's proposition to test steel castings chiefly by means of test bars rolled from test ingots is surprising. The important things about a steel casting are (1) its freedom from cavities; (2) its chemical composition; and (3) the physical condition of the metal in the casting itself. Rolled test pieces do little more than tell of the chemical composition. Cavities close to a great extent in rolling, and the physical condition of the rolled metal tells us very little indeed of that of the castings which happen to have been made from the same charge. The physical condition of a rolled test bar is influenced profoundly by its rolling and the accompanying heat treatment, influences to which the casting is not exposed at all.

Test coupons, cast on a casting, and heat treated with it, tell quite as well as rolled bars do about the chemical composition; they give direct and very valuable information as to the physical condition of the castings, as affected by its casting temperature and subsequent heat treatment, and, if judiciously placed, they may give information as to its freedom from cavities. As to this latter point, important in-

* "Uber das Verhalten der Thomasstahlschienen im Betriebe." L. Tetmajer.

Mr. Howe. formation may often be had by ascertaining the density of the whole casting, either by its weight and dimensions, or, if it be small, by weighing it first in air, then in water; and also by examining the parts where the heads and runners are cut off. When castings are made in large numbers from a single pattern, the best possible information may often be obtained as to their value by testing to destruction whole castings chosen at random. This is done, for instance, in case of car-coupler knuckles.

The direction that castings of simple form be used without annealing is astonishing. What is its purpose? Are steel founders who are skillful and careful in annealing to be deprived of the advantage of their skill and care? Are users to be deprived of the advantages of annealing? That such a provision might be acceptable in special cases, where a material intermediate in merit between cast-iron and annealed steel castings would suffice, can be understood by the writer, but such cases are not the rule.

He does not agree with the author that it is absurd to limit the carbon content of steel; that Mr. Riley's conclusions are not in accord with his premises; or that the recommendation to use the terms "yield-point" and "elastic limit" in their strict sense is unwise. Does the author forget that "elastic limit" was used as a physical term long before it had any commercial use, and that its scientific use has continued? It cannot be seen how he can escape from the fact that the term "yield-point" is unmistakable, while "elastic limit," if used in the way he prefers, is certainly ambiguous.

His recommendation that the material used for bridges should be even weaker than now seems in the wrong direction. The sacrifice of strength to a degree of ductility far greater than the metal can ever be called on to display in normal use, and which therefore is useless except to resist barbarous maltreatment, seems unwise. The wiser course is to move in the direction of using stronger material, and, by greater care in its treatment, to render such extreme ductility superfluous.

Mr Hartshorne JOSEPH HARTSHORNE, Esq.—On account of the writer's former connection with the only company which has operated the basic Bessemer process in this country upon a commercial scale for a term of years, he feels in duty bound to defend it.

The author has quoted from Mr. A. E. Hunt a sweeping condemnation of Bessemer metal for structural purposes, and has fortified it by quotations from Messrs. J. W. Wailes and W. H. White. The writer is strongly inclined to agree with the opinion of these gentlemen in respect to the Bessemer process, as usually carried out in this country and in England. It would, he is sure, meet with a vigorous denial from such manufacturers as the John Cockerill Company. Even were this opinion a universal truth, as applied to the acid Bessemer, it would not be fair to transfer it unquestioned to the basic Bessemer process, which should be considered solely on its own merits.

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The author calmly annihilates the basic process in the following words: "The objections to Bessemer steel are many times emphasized in the product of the basic converter, for at the end of the operation there is often a very considerable percentage of phosphorus that passes back from slag to metal, and which is not always uniformly distributed. This fact utterly condemns it for the best of work." He then gives the reasons why this rephosphorization occurs in the basic Bessemer and not in the basic open-hearth process.

It is with this *ex cathredra* edict of condemnation that issue must be taken. When the basic Bessemer process is improperly and carelessly carried out there is always danger of rephosphorization. In the early days at Pottstown they suffered from it in common with most beginners, but the same is true of the basic open-hearth process.

The writer asserts positively, from personal knowledge and experience, that when the proper conditions are observed there is no more danger of rephosphorization in the basic Bessemer than in the basic open-hearth process. On the other hand the basic process produces metal which is better in many ways than that usually made in the acid converter. It is freer from sulphur and phosphorus in the average, and can be made freer from these elements than that which is made from the best selected acid stock. The soft steels can be made lower in carbon and lower in manganese than any acid Bessemer steel he ever heard of. It is more solid and freer from blow-holes in the ingot than acid Bessemer steel. Actual observations confirm this statement, which would be expected from the fact that properly made and cast basic Bessemer steel does not require to be capped in the molds, no matter how soft it is. It is less likely to be red-short from oxides or oxygen, or whatever it is that is corrected by manganese, and requires less manganese to be added to make it fit for use. One heat which had less than 0.10% of manganese in the finished material and was cast in 12-in. molds, was not capped at all and rolled perfectly into wire billets. That these assertions are true as to the characteristics of basic Bessemer as compared with acid Bessemer soft steel can be affirmed from an experience of 6 years with the former process and 10 years with the latter, together with much study of both processes in Europe.

Since the basic Bessemer process has reached its greatest state of development in Germany and Austria, it is natural that there also has this question of quality been most closely studied and reported upon. One of the most complete and convincing investigations on this subject is that by Professor L. Tetmajer, Director of the Testing Laboratory of the Polytechnical School of Zurich,* entitled, "A Contribution to the Soft Steel Question." Professor Tetmajer was formerly not a believer in the use of soft steel, and especially of basic Bessemer steel, for bridge-building. He saw reason to change this belief, and formulated his conversion as follows:

* See *Stahl und Eisen*, 1892, p. 558.

Mr Hartshorne "Recent investigations have shown that the much-feared unreliability, which is often caused by wrong treatment of the material in the work shop, is by no means an attribute of basic Bessemer steel alone, but occurs just as often in open-hearth steel; also that, owing to the progress made in the management and control of the basic Bessemer process, the certainty with which structural steel of any desired chemical and physical quality can be made, and the established fact that many failures are due to causes lying outside of the process proper, we are no longer justified in making a distinction between open-hearth and basic Bessemer steel for structural purposes. * * * Basic Bessemer steel can be made in the soft grades necessary for structural and bridge work with a certainty and regularity, as regards chemical composition and mechanical properties, in no way inferior to that of the open-hearth process."

This opinion is based on the following investigations:

A. Tests made on 100 heats, 700 tonnes, produced by the Prager Eisenindustrie Gesellschaft, at Kladno, for a bridge at Melnik. Phosphorus was below 0.05% in all of this.

B. Chemical analyses of 48 consecutive heats made at Kladno before the Austrian Committee on Ingot Metal. Phosphorus between 0.021 and 0.032 per cent.

C. Inspection of material from the Rothe Erde Works, near Aix-la-Chapelle, for a bridge for the Wriezen-Jaedecker Railroad, 1891. Eighty-three heats, 800 tonnes of material. Phosphorus between 0.03 and 0.08%, 249 tension tests and numerous other ones were made. No tests that did not come within the specifications. No rejections from any cause.

D. Experiments made by the management of the Royal Railways of Bromberg, at the Rothe Erde Works. One thousand seven hundred pieces, representing several thousand tonnes, were examined. Sixty-one heats showed phosphorus between 0.023 and 0.093 per cent. All of the bending and breaking tests were faultless.

E. An examination of one year's product of beams for railroad cars at the Salgo-Tarjan Works, covering 100 heats, with 247 tension tests and the usual bending tests. Out of these heats only two exceeded 4.5 tonnes per square centimeter (63 990 lbs. per square inch).

F. Results of the tests made to date on the material for the bridge over the Vistula at Fordon. Three hundred heats from Rothe Erde Works tested with no rejections. Ultimate strength between 3.9 and 4.5 tonnes per square centimeter (55 458 and 63 990 lbs. per square inch); elongation, from 20 to 32%; phosphorus, below 0.10 per cent. All bending tests flawless.

G. Inspection of material for bridges for the St. Gothard Railroad, the steel coming from De Wendel's works at Hyange. There were 1 571.4 tonnes of structural material, and 61.6 tonnes of rivet material made from 374 heats. No rejections.

Professor Tetmajer also comes to the following conclusions: It is

more difficult to get good steel from the basic Bessemer process; the variations between the chemical composition of ingots generally fall within the allowable limits of error in analysis; the last ingot may have too much manganese if the ferro-manganese added remains unmelted; there is no difference in the position of the blow holes in the basic Bessemer and open-hearth metal, provided the chemical composition, the deoxidizers added and the casting temperatures be the same in both instances. He says finally: "The opinion that open-hearth metal is more solid than basic Bessemer metal is erroneous, and is flatly contradicted by our numerous tests on boiler plates from various open-hearth works." Mr Hartshorne

Professor Tetmajer has also published a paper* on "Basic Bessemer Metal as Rivet Material." These rivets were for bridges of the St. Gothard Railroad, and of the Swiss Northeastern Railroad. They were rolled, made and stored by heats, so that full control was possible. Tests ingots were taken during the casting of the third or fourth ingot, from which a tension test and chemical analysis were made. The latter were checked at Zurich, at first on every heat, later on every two heats. The following tests were made on two rods taken from different ingots of each heat, namely, a tension test, a cold bending test in the condition as delivered, a similar test after quenching, a similar test after being nicked, a hot bending test, and two upsetting tests. All of the heats were below 0.09% in phosphorus, 47 below 0.07%, and 36 below 0.06 per cent. All of them were below 4.2 tonnes per square centimeter (59 724 lbs. per square inch), and 36 below 3.9 tonnes per square centimeter (55 458 lbs. per square inch); all of them were above 26% in elongation and 24 were above 30 per cent. As a result of his investigations Professor Tetmajer comes to the conclusion that the basic Bessemer process can be carried out with sufficiently complete regularity and certainty, when properly conducted and superintended.

A very complete investigation of basic Bessemer metal was made in connection with the bridge over the Vistula at Fordon, which was reported upon by George C. Mehrtens, Government Railroad Director at Bromberg.† This investigation is especially interesting as it also included open-hearth metal for the same bridge. Seven hundred heats of basic Bessemer metal were tested, and 508 heats of open-hearth metal. None of the Bessemer heats were rejected, while 16 of the open-hearth heats could be not accepted. The system of testing was most exhaustive.

Samples of finished material were taken from three different ingots of each heat, and the following test made from each of them: a drawing-out test, a cold bending test, a bending test after quenching, a

* See *Stahl und Eisen*, 1893, p. 625.

† See *Stahl und Eisen*, 1892, p. 593, and 1893, p. 275.

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flattening and bending test, and a tension test. There were, therefore, as a general rule, 15 different tests made on each heat. Photographs of these tests have been reproduced in Mr. Mehrtens' paper before the International Engineering Congress in Chicago.*

Besides the three ordinary tension tests, two extra ones were taken from different ingots on every tenth heat. Carbon, phosphorus and manganese were determined in each heat, and silicon and sulphur in every tenth heat. Besides the above-mentioned tests, there were others made, as shown in the photographs referred to. These were bending, hot and cold drifting, and drop tests.

All of the 700 basic Bessemer heats were below 0.10% in phosphorus, 633 were below 0.08%, and 303 were below 0.06 per cent. All of them were below 43.8 tonnes per square centimeter (62 284 lbs. per square inch), in ultimate strength, 636 were below 43.0 tonnes per square centimeter (61 146 lbs. per square inch), and 550 were below 42.0 tonnes per square centimeter (59 724 lbs. per square inch). All of them were above 21% elongation, all but one above 23%, 682 were above 25%, 316 were above 28 per cent. All but one of the 508 open-hearth heats were below 0.08% in phosphorus, and 489 were below 0.06 per cent. All but two of them were below 45.0 tonnes per square centimeter (63 990 lbs. per square inch); 408 were below 43 tonnes (61 146 lbs.), and 187 were below 42 tonnes (59 724 lbs.). All but one heat were above 20% elongation, 471 heats were above 23%, and 262 were above 28 per cent.

Very complete and interesting tables of the results of the tests and analyses accompany this paper, which go into the subject in great detail. Mr. Mehrtens concludes as follows: "Whoever sufficiently studies the above plates and tables will reach the conclusion that no longer can any objection exist to the use of a good soft steel, and that basic Bessemer (Thomas) metal has become the equal of open-hearth metal."

Coming to the writer's own experience, he can say that it has led to the same conclusions as those enunciated by Mr. Mehrtens and Prof. Tetmajer. Unfortunately the records of the steel works of the Pottstown Iron Company are not now accessible, and he cannot, therefore, produce as much corroborative evidence as he otherwise would be able to, and will have to depend somewhat on his memory.

During the early days of the work at Pottstown, there was undoubtedly trouble from rephosphorization, and a good deal of time and labor was spent investigating its causes. It was due, in a large measure, to a thin slag, whether the latter was owing to too high a temperature, or to a low melting point caused by too low a basicity. Acting on this information, and taking other precautions, it was possible to prevent rephosphorization to any appreciable extent. The presence of enough lime was first insured to make the slag sufficiently

* See the *Transactions* of the American Society of Civil Engineers, Vol. XXX, p. 204.

basic under all conditions, and the temperature of the blow was regulated so as to keep the slag below the danger point. It was sufficient, for prevention of rephosphorization, to chill off the slag. During the last three years of work at this plant no direct evidence of rephosphorization was found, either in the vessel or in the ladle. During the last 18 months 80.52% of the product was below 0.06% of phosphorus, 17.63% was between 0.06 and 0.10, and 1.85% was above 0.10. It must be remembered that some of the product was of such a character that 0.12% phosphorus was not objectionable, and that it is cheaper to stop the after-blow as soon as possible. For the last six months there was 86.68% of the product below 0.06%, 12.44% between 0.06 and 0.10%, and 0.88% above 10% of phosphorus. About one-half of the product was 0.04% or less. There was no difficulty in getting below 0.03% in phosphorus, when it was necessary to do so. Mr Hartshorne

Many analyses were made to test the regularity of the steel in the different ingots of a heat. One series of such analyses is given as typical of them all; it may seem to show slight rephosphorization.

TABLE No. 1.

Blow No.	Ingot No.	C.	P.	Mn.
6997	1	0.09	0.040	0.630
	2	0.10	0.030	0.740
	3	0.11	0.040	0.650
	4	0.09	0.035	0.650
6998	1	0.08	0.035	0.325
	2	0.08	0.030	0.320
	3	0.08	0.030	0.325
	4	0.08	0.040	0.300
6999	1	0.08	0.045	0.415
	2	0.08	0.035	0.425
	3	0.08	0.050	0.405
	4	0.08	0.035	0.415
7000	1	0·10	0.035	0.425
	2	0.10	0.050	0.390
	3	0.11	0.055	0.455
	4	0.10	0.055	0.445

It will be noticed that the first ingot of the last two heats is lower than the others. This may indicate rephosphorization, but probably indicates segregation. If the former were the case, it should increase in the later ingots, as this trouble is cumulative. This, however, has not happened.

An example is also given of a number of more complete investigations which were made as to the regularity of the steel. The ingots were 16½ x 20½ x 78 ins., and were rolled into slabs 19½ x 2½ ins. in section. Samples for analysis were taken every 4 ft., beginning 2 ft. from the top end.

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TABLE No. 2.

Ingot No.	Sample No.	C.	S.	P.	Mn.
First ingot cast	1	0.06	0.030	0.020	0.205
	2	0.06	.....	0.020	0.205
	3	0.06	.....	0.020	0.210
	4	0.07	.....	0.020	0.215
	5	0.06	.....	0.020	0.220
	6	0.06	.....	0.030	0.220
	7	0.07	.....	0.030	0.230
	8	0.06	.....	0.020	0.195
Second ingot cast	9	0.06	0.030	0.025	0.205
	10	0.05	.....	0.025	0.210
	11	0.05	.....	0.025	0.210
	12	0.07	.....	0.025	0.210
	13	0.05	.....	0.030	0.220
	14	0.05	.....	0.020	0.225
	15	0.07	.....	0.030	0.210
	16	0.07	.....	0.020	0.210
Third ingot cast	17	0.06	0.029	0.025	0.205
	18	0.07	.....	0.025	0.210
	19	0.06	.....	0.020	0.205
	20	0.07	.....	0.025	0.200
	21	0.07	.....	0.020	0.210
	22	0.07	.....	0.020	0.205
	23	0.07	.....	0.025	0.210
	24	0.07	.....	0.020	0.220
Fourth ingot cast	25	0.07	0.033	0.025	0.190
	26	0.07	.....	0.025	0.175
	27	0.06	.....	0.025	0.175
	28	0.07	.....	0.025	0.215
	29	0.07	.....	0.020	0.190
	30	0.06	.....	0.025	0.195
	31	0.07	.....	0.025	0.180
	32	0.07	.....	0.025	0.200

Many such series of analyses as those given in these two tables were made, all of which showed about the same results, and none furnished any more evidence of rephosphorization. The physical qualities of the steel, when properly handled at the casting pit and in the rolling mills, followed very closely the chemical composition. Mr. William R. Webster has shown this very completely in his papers* before the American Institute of Mining Engineers and the British Iron and Steel Institute. The tables of tension tests there given show the physical quality of the steel most completely. It is not worth while to repeat any of them here. They show the same general result as those quoted from the German sources. The above data will show most conclusively that basic Bessemer steel, when properly made, with due care and knowledge, is fully equal to open-hearth steel of like chemical composition, when made with like skill and carefulness.

For the purpose of eliminating the danger of segregation, the objectionable elements, especially sulphur and phosphorus, should be made so low that, should the entire amount be concentrated in half of

* See the *Transactions* of the American Institute of Mining Engineers, Vol. XXI, p. 766, and Vol. XXIII, p. 113; also the *Journal* of the Iron and Steel Institute, 1894, Vol. I, p. 328.

the ingot, the steel would still be within the limits. This is the only method of preventing the bad results of segregation which present knowledge reveals. The author has stated very clearly the effect of the various elements in steel, and the writer's experience agrees with his in general. On one or two points, however, it differs. Sulphur appears to increase slightly the tensile strength of plates, while, as the paper states, it does not seem to effect the elastic limit, elongation or reduction. Mr. Webster's investigations show quite clearly that manganese does increase the tensile strength of soft steels, but that its influence per unit is lessened as its content increases. Mr Hartshorne

In the experience at Pottstown, it was found that phosphorus did effect the elongation, as well as the tensile strength, of test pieces cut from plates. When ¾-in. round rods are tested, it often seems not to have any appreciable influence, even when present in amounts too high to be permissible in structural steel.

The writer agrees with the paper thoroughly in thinking it better practice to cast large ingots and then bloom them to slabs before rolling into plates, but his reasons for thinking so are purely what might be called matters of economy and convenience. The experience of the American plate mills has certainly shown that just as good plates can be rolled direct from an ingot as those which are rolled from a bloom. The decision between these two methods of procedure will be decided in most cases by the answer to the question as to what costs most in the end. Experience has led him to believe that, after enough work has been done on an ingot to close up the blow holes and to bring the grains in close relation to each other, further work has no effect as such. It is only necessary that this work should be done at a temperature below Chernoff's point *b*, that is, the point below which steel does not change its structure. Any work which is done beyond that strictly necessary for consolidation has its effect solely as it determines the temperature at which the metal operated upon leaves the rolls or hammer. In this belief he has only followed the path pointed out by Mr. James Riley, as cited in the paper. Mr. Riley was and is right in the position he then took. He is certainly strongly supported by the investigations of Messrs. Sauveur, Webster and others.

It is not yet settled that segregation is greater in large than in small ingots, and there is some evidence that the reverse may be the case. As the author suggests, it is an easy matter to cut the part most effected by segregation into scrap. If this is too heroic an operation, it can at least be used for an inferior finished product. The author has incidentally remarked that the difference in cost in favor of the basic hearth disappears when steel with over 0.08% phosphorus is being made. This is too sweeping an assertion, as it is largely a question of locality, depending for its answer on the cost of pig and scrap. In one instance there was at least a dollar a ton in favor of the basic hearth for the cheapest grades of steel.

Mr. Greiner. J. E. GREINER, M. Am. Soc. C. E.—Specifications for structural steel, no matter how carefully or by whom drawn, will have certain features more or less subject to criticism. As to the method of manufacture, there can be no question, since open-hearth steel, whether it be basic or acid, is the only material which any engineer is justified in using in structures subject to vibrations or shocks.

There is still a lurking skepticism as to the superior quality of the basic open-hearth metal, owing to an inferior grade of stock which is used, but the writer has not as yet been able to offer any objections to any soft basic steel which has been made during the past two years for various structures built on the lines of the road with which he is connected, although this material is subject to severe punching and drifting tests in addition to the ordinary specification requirements. He has, however, met with a case of acid open-hearth steel having an ultimate strength slightly above the upper limit of soft steel requirements, which when rolled into a channel and built up into a post under the same conditions as wrought iron, showed a crack through one flange across the web to the root of the other flange. It is certain that this crack was not in the material before it left the shop, and the channel must have cracked either during the unloading at the bridge site or during transportation. This is the only case, however, of failure of open-hearth steel which has ever come to the writer's notice, and the cause of this failure could not be traced, although careful tests and chemical analyses were made of the channel adjacent to the fracture and of different parts throughout its length.

Manufacturers who make acid steel exclusively naturally believe that the product of the acid furnace is superior to that of the basic, no matter whether a soft or medium steel is required; but it has been found extremely difficult to obtain an acid steel which will always meet the specification requirements of soft steel, the tendency being to run over 60 000 lbs. in ultimate strength, and when any question is raised about the acceptance or rejection of material which is too high, the manufacturer will invariably argue that the acid steel, even when it goes far above specification requirements, would be better than a basic steel owing to the greater certainty of uniformity in the material itself. Should this same manufacturer roll his shapes from basic billets and the tests fall below specification requirements, he will argue that it is the best material to use, because it is much softer and can be manipulated in the shop without any danger of injury, and would be better able to stand the wear and tear of heavy traffic when placed in a bridge.

So far as a chemical analysis is concerned, it is the writer's practice to limit the phosphorus to 0.08% for acid and to 0.05% for basic metal, and to make a sufficient number of punching, drifting, bending and quenching tests to be reasonably certain that there is no

excess of injurious elements, and satisfy himself that the material is perfectly safe for all structural purposes. Mr. Greiner.

It is extremely unfortunate that there is no good way of applying satisfactory shock tests, as strains due to shock are what engineers fear more than anything else. It is rather peculiar that when bars which have stood 25 to 30 years in a bridge break on account of excessive loading, they break suddenly and without warning, and show neither a reduction of area or elongation, and generally have a granular or crystalline fracture. If a suitable impact machine were designed to thoroughly test metal for shocks, punching, drifting, bending and quenching, the writer would give much more consideration to such tests than to the ordinary elastic limit, ultimate strength and reduction of elongation of test pieces regularly made for purposes of record. When the usual excellent qualities of soft steel are recognized, this grade of material will be worked in the shops just as wrought iron is worked, and at the same time safe working stresses will be increased from 10 to 15 per cent. When medium steel is used, it is generally rolled into eye-bars, which, after being annealed, practically converts the material into a soft grade of steel, and while, therefore, some specifications require soft steel in all shapes and plates and medium steel for eye-bars, the bridge will practically contain nothing but soft steel. When it is desired to use high working stresses so as to cut down the dead weight in long spans, a medium grade of steel having all sheared edges planed off, and all holes drilled, is the best practice.

The author of the paper must not think that engineers are ignorant of the tricks practiced by the manufacturers, and if inspectors allow the manufacturers to select the most favorable parts of their plates or shapes for testing purposes, it is done with open eyes, although it would be an easy matter to so frame the specifications as to make the selection of test pieces rest entirely with the inspector, who could then select a plate or shape rolled the full length, out of any lot of material, and have it cut up into test pieces under his own supervision. This, however, is a degree of refinement not usually practiced unless the employees of certain manufactories have demonstrated by their tricky practices that it is absolutely necessary to take such extraordinary precaution.

Concerning the author's specifications, little need be said except perhaps that there are too many shades of differences in the physical requirements. When soft bridge steel is specified, it should be sufficient to give an upper and a lower limit varying by 8 000 lbs., and all material can be made to come within these limits without any difficulty. The writer, however, would place the lower limit at 52 000 lbs., and the upper at 60 000 lbs., instead of 47 000 lbs. and 58 000 lbs., as given by the author of the paper, and for medium steel he would place the limits between 60 000 and 68 000 lbs., instead of between 53 000

Mr. Greiner. and 64 000 lbs. The author's hard steel is practically what is usually considered a medium bridge steel, and the writer can see no good reason for changing the name.

Mr. Goldmark. HENRY GOLDMARK, M. Am. Soc. C. E.—It is satisfactory to learn that, even from the standpoint of a metallurgist, the specifications now in use are not unduly burdensome. For practical reasons it is desir-

TESTS OF DIFFERENT INGOTS OF THE SAME HEAT.—ACID OPEN-HEARTH STEEL.

Heat Number.	Ingot.	C.	Elastic limit. Pounds per square inch.	Ultimate strength. Pounds per square inch.	Elongation. Percentage in 8 ins.	Reduction of area. Per cent.
4 526	1	0.25	56 660	78 700	25.0	53.3
	1	.....	54 270	78 500	25.0	55.3
	2	0.22	51 070	74 070	25.0	58.2
	2	.....	51 560	74 700	25.7	55.5
	3	0.21	53 490	76 070	25.5	58?6
	3	.....	52 570	74 770	26.0	59.0
	4	0.22	47 320	72 180	25.5	55.5
	4	.....	46 500	72 150	27.2	58.6
	5	0.21	46 370	73 530	24.0	52.7
	5	.....	46 130	73 750	27.0	58.8
	6	0.21	47 420	72 130	27.0	55.5
	6	.....	47 960	70 360	26.5	56.5
4 532	1	.....	54 000	85 780	21.3	44.8
	1	.....	53 070	86 300	23.2	44.8
	2	.....	53 930	83 760	24.6	56.4
	2	.....	54 720	83 420	24.0	54.7
4 533	1	0.35	51 390	81 340	23.5	48.7
	1	.....	51 470	81 300	23.7	46.0
	2	0.34	49 270	80 800	25.0	54.1
	2	.....	49 630	81 360	25.7	54.9
	3	0.35	51 380	84 240	24.7	52.4
	3	.....	51 970	83 200	24.0	52.3
	4	0.37	48 820	83 660	23.0	44 5
	4	.....	50 780	84 420	22.5	41.4
	5	0.35	51 930	83 760	23.5	45.0
	5	.....	50 700	84 200	22.3	49.5
	6	0.35	54 210	83 760	22.7	43.6
	6	.....	55 270	84 640	22.8	46.9
	7	.....	49 500	81 240	22.7	48.6
	7	.....	51 110	82 080	24.9	50.0
	8	.....	50 200	81 760	24.8	48.3
	8	.....	51 190	82 480	23.3	48.3
	9	.....	49 130	82 560	22.7	46.2
	9	.....	50 960	82 460	22.3	44.7
	10	0.34	52 530	82 980	23.0	45.3
	10	.....	53 525	84 100	22.5	44.9
*	10	.....	49 690	80 170	22.0	51.2
4 536	1	0.22	54 860	78 170	25.1	56.0
	1	.....	55 670	78 810	24.6	57.6
	2	0.23	50 750	76 730	25.2	54.1
	2	.....	50 870	76 860	23.9	54.0
	3	0.25	54 100	76 220	26.2	53.4
	3	.....	49 700	77 230	25.0	54.0
	4	0.21	48 450	77 280	24.2	56.7
	4	.....	48 780	78 090	25.7	57.3
	5	0.22	47 740	74 180	27.0	54.5
	5	.....	47 520	74 490	26.2	54.6
	6	.....	50 600	78 820	23.9	49.4
	6	.....	51 650	79 050	25.0	46.3
	7	0.22	50 570	75 710	25.3	52.7
	7	0.23	51 310	76 300	25.0	50.1
*	7	.....	47 530	72 420	21.6	56.6

* Annealed.

able that the methods employed in testing shall be simple and uniform, as the refined appliances of the laboratory are clearly out of place in the every-day routine of the commercial testing room. Mr. Goldmark.

Besides this, complicated and unusual specifications involve considerable extra expense, so that it is to the interest of the consumer to do away with them as much as is possible, without impairing the quality of the material. For these reasons it is very important to know how closely ordinary methods enable a judgment to be made of the material to be used. Extended chemical and physical investigations on the different grades of steel are greatly needed in this field, and would amply repay the time and money expended on them.

In the meantime something may be done by engineers in charge of these testing laboratories to supplement their ordinary work by such additional tests as can be easily made from material at hand. As all testing must necessarily be done by sample, any information as to the degree of uniformity that prevails in the metal is of value. In the case of steel, the "blow" or "heat" is the natural unit, and it is, further, usual to confine the test to a single ingot. The tests given on the opposite page were made to determine the amount of variation likely to prevail in different ingots of the same cast, and are considered of sufficient value to be put on record. The results are quite satisfactory and indicate that the variation of 8 000 lbs. in the ultimate strength usually allowed is fair to the maker, while not excessive from the engineer's standpoint. The test pieces were ¾-in. rounds made from 20-in. square ingots, and were not machined. The duplicate tests of each ingot are from the same rod.

HENRY B. SEAMAN, M. Am. Soc. C. E.—The paper presents an accumulation of data which is particularly valuable as corroborating conclusions already reached. For instance, the data as to speed of testing shows that below the author's proposed minimum the speed of testing has little effect upon the practical result. His proposition to regulate the time of testing by the speed of screws, however, is not practicable, because it does not regulate the rate of increase of the applied strain per square inch. The screw speed, when applied to a specimen 6 or 8 ins. between shoulders, would produce a far greater strain than if applied to a specimen without shoulders and with the jaws of the testing machine 12 to 14 ins. apart, and finally, when applied to full-size bars, varying from 4 to 40 ft. in length, it is entirely impracticable. The true criterion is pounds per square inch per minute, and from this the inspector must deduce the speed of his machine, either by calculation or by direct readings of applied strain. Even the minimum speed proposed by the author is too rapid to give any reliable intermediate data on short specimens, and will serve to raise all results except stretch. The proposition of Mr. Lewis to abandon intermediate data, is perhaps prompted by this thought. Mr. Seaman.

Mr. Seaman. Some years ago, when the question first arose as to whether engineers should specify the chemical composition of steel, the inclination was to leave this to the contractor. In order to thoroughly test the finished product, the uniformity as well as the strength and ductility of the entire product must be demonstrated. The disclosures made by the author in regard to the practice of hoodwinking inspectors, is, at least, startling. He repeatedly states "this is not dishonest." What, then, shall be the standard of integrity?

If steel is so variable in each piece as the author indicates, how can the uniformity of the entire pile be judged? He writes:

> "If every plate is to be tested, then a coupon is left upon each corner, and a contiguous strip is privately" (*i. e.* secretly) "tested by the maker. After finding which corner gives the best results, the other coupons are cut off and the plate submitted to the inspector. This is not dishonest, for any one corner represents the plate just as much as any other corner, and it would manifestly be unfair to designate from which corner the test is to be taken."

And yet this is just what the manufacturer does by this practice. He "designates from which corner the test is to be taken." It is the engineer's duty, not only to design the structure, but to see that it is built as designed, and that no single member is deficient in strength. To accomplish this, it is necessary, either to test every piece, or to be otherwise assured by its uniformity, that the testing which is done exposes the worst material used. How is this possible, with the practice outlined by the author? Such practice cannot be too severely censured. The yield point is higher than the elastic limit, and will more readily fill the specifications. The limit of elasticity is that point of strain beyond which the material will not recover its former state upon the removal of the applied load. An inspector of one large trunk line still continues to test this point by the removal of the load when the prescribed limit is reached, and the writer considered this practice correct. As a matter of fact the elastic limit is now rarely found in testing, but the yield-point instead as indicated by the drop of the beam.

In reading the author's suggestion as to a sliding scale for the required ultimate strength of various specimens, the writer has wondered whether the author anticipated a corresponding sliding scale of allowable strains in engineers' offices. He seemed to forget that material is rolled to fulfill the requirements of the structure already designed, and that the structure is not designed to use up the various grades of marketable material.

Mr. Deans. JOHN STERLING DEANS, M. Am. Soc. C. E.—The Society has rarely before it for discussion more important subjects than those of uniform methods of testing and standard specifications for structural material. Both the engineer and the manufacturer are equally concerned, and this is evidenced by the unusual interest taken in the report and paper just presented. It is seldom a paper covers the ground so satisfactorily

as this ; it presents facts well known to the manufacturer and to those engineers who have had special advantages enabling them to gather this particular information and experience; but to the majority it will be the first time that the reasonableness of the appeal of the manufacturer, that a "uniform specification" and a "possible specification" be decided upon and adhered to, has been presented to them in a full, concise and convincing manner. To those engineers who have been content with tests of the finished material, not caring to be informed as to the mode of manufacture, the facts brought out will have peculiar force. These engineers will certainly hesitate to use a product which lacks uniformity and reliability, even though individual specimens may fulfill their specifications. As has been said by a well-known authority, in speaking of steel, "the unexplained failures can invariably be traced to the Bessemer product." Open-hearth steel has proved its superiority as a reliable metal of uniform quality in so many instances, that its claims upon the confidence of the engineer will at this day hardly be disputed. It is certainly a more expensive metal, and the engineers should protect those steel-makers and manufacturers who propose to give them the best product, against the cheaper and inferior material; or, if they decide, for special reasons, to accept the inferior metal, they should see to it that they receive the benefit of the reduced cost. Several construction companies have long felt this handicap, and have been waiting for engineers to appreciate the difference in the reliability of the two products, and also the difference in their cost and value. Mr. Deans.

Referring to the question of specifying the chemical composition, it hardly seems necessary or proper to limit a steel-maker to any special percentage of the various elements, except in the case of those elements which, being present, would cause injury, and at the same time could not be determined by the physical test if present to an injurious extent.

In the case of phosphorus, this element may be present to an injurious extent, and the fact will not be shown by the most rigid ordinary physical specification. It would therefore seem most reasonable to limit the quantity of this element to a point below which it will have no deleterious effect on the metal, either during its manipulation in the mill or shop, or in actual use in the completed structure. This requirement is necessary to protect the engineer in his design, and it does not place upon the manufacturer of any section an unnecessary restriction. In no other way than by a combination of the physical requirements with this chemical test has the manufacturer been able to guarantee the product of his furnace as a metal of unquestioned reliability.

For the above reasons it seems not only unnecessary to give a more complete chemical specification, but, in addition, such complete speci-

Mr. Deans. fication would result in harm in tying the hands of the producer to just this extra extent, give an unjust advantage to particular plants, and increase unnecessarily the cost to all without any corresponding advantage either in material or structure.

Referring to the physical requirements, if this discussion is to have permanent value, it will lead to the more general use of the best grade of material for our engineering structures and to the reduction in the number of grades of material to the best, and certainly to not more than two. Reference is now made to structural material alone, and not to material for tools and other special purposes. In fact, there may be special cases, even in engineering structures, where it might be advisable for the engineer to specify special grades of material for the several parts. These special cases should be taken up as they occur. The object of this discussion is to settle upon some uniform specification and grades of material for the general and ordinary engineering structures.

Good practice is certainly tending toward a softer metal than what was considered best, even at a very late period; still it does not seem necessary to go as low as 50 000 to 58 000 lbs. ultimate strength to secure a tough, ductile steel of sufficiently high elastic limit to warrant the increased allowable strain per square inch in designing the structures.

Basic open-hearth steel is surely taking its deserved position as a structural material and on equal terms, at least, with acid open-hearth, a position not accorded to it until very recently. When steel first came into use, it was thought desirable to use a higher steel for compression members than that used for tension members; this practice has gradually disappeared, both finished structures and experiments showing no special advantage in the use of the different grades. Such specifications caused confusion in the shops, and the greatest care to see that the various grades of metal were used in the proper members.

The paper does not suggest the adoption of 12 different grades of structural material; the writer is strongly opposed to any such suggestion; one standard grade would seem to be ample, and he would suggest the following:

Open-hearth steel..	Ultimate strength, 57 000 to 65 000 lbs. per square inch.
	Elastic limit not less than 32 000 lbs. per square inch.
	Elongation in 8 ins., 25 per cent.
	Reduction of area, 45 per cent.
	Phosphorus not over 0.06% for acid steel.
	Phosphorus not over 0.04% for basic steel.

The above modified for rivet steel to an ultimate strength of not over 57 000 lbs per square inch.

For wide plates..
- Under 42 ins., as above.
- Over 72 ins..
  - Ultimate strength, as above.
  - Elastic limit, as above.
  - Elongation in 8 ins., 22 per cent.
  - Reduction in area, 40 per cent.

Usual bending tests in all cases.

The above will fulfill every ordinary requirement of an engineer. It is a grade that will not be injured by manipulation in the shop. Above certain thicknesses, holes should be drilled or punched and reamed, and sheared edges planed, like wrought iron, for extra thicknesses.

The above test should be determined by test pieces 12 ins. long, $\frac{1}{2}$ sq. in. in cross-section, and not less than $\frac{1}{4}$ in. thick, cut from a finished bar. Most knowledge of steel has been obtained by the experiments made with test pieces of this size, and, unless there is some special reason, it is desirable to retain these dimensions.

Referring to the author's suggestions concerning steel castings, there seems to be no good reason for specifying more than one grade for the castings used in ordinary practice, and the following is suggested:

Acid open-hearth steel.
- Ultimate strength, 57 000 to 67 000 lbs. per square inch.
- Elastic limit, 36 000 lbs. per square inch.
- Elongation in 4 ins., 20 per cent.
- Reduction of area, 25 per cent.
- Phosphorus, below 0.06 per cent.

The above to be determined by a $\frac{3}{4}$-in. round test piece 4 ins. between shoulders, cut from a casting and not annealed.

Regarding the value of the reduction of area of the fractured section as an indication of the quality of the material, it is of the least value of all of the physical requirements. A high reduction may, and often is, obtained in testing material of very irregular quality. The relative values of the physical requirements may be placed in the following order: Elastic limit, elongation, ultimate strength, and reduction of area.

There seems to be no good reason for changing the name of elastic limit to yield point, in discussing and deciding upon specifications for a standard grade of material to be determined by practical testing in the ordinary manner. No confusion has, so far, occurred by the popular use of this term. When used in connection with matters concerning ordinary tests it naturally assumes its peculiar meaning for this case, while the term used in connection with the more elaborate and refined investigations would immediately assume its more exact significance.

Mr. Deans. The recommendation that bending tests be made by pressure, rather than with blows, is a wise suggestion; in no other manner can results be obtained which can properly be compared, and upon which reasonable conclusions can be based.

It certainly seems to be a needless refinement at this day, to specify four grades of wrought iron. One grade with an elastic limit of 26 000 lbs., an ultimate strength of 50 000 lbs., an elongation of 20% in 8 ins., and a reduction in area of 30%, with slight modifications in elongation and reduction for wide plates, would certainly appear to be ample for all requirements.

There is no good reason for specifying a quenching test for steel, to be used in ordinary engineering structures. It is not a condition to which the finished product will be subjected, and, as it does not add to the information obtained by the other proposed physical tests, it appears to be an unnecessary requirement. There is no reason why the percentage of elongation and reduction of area should not be given in a fixed quantity, the same as the elastic limit. They do fluctuate, of course, with the ultimate strength, but this takes care of itself in the specifications given, and by naming fixed requirements, the labor of making a calculation of each test is avoided, which is something to be considered in these busy days.

It may appear to many that the suggestion of fixing upon one standard grade is rather a bold one, and tends to reduce the resources of the engineer. When it is borne in mind that this is only a suggestion for the regular ordinary trade work, the suggestion may appear less unreasonable. For structures of great magnitude, involving peculiar features, and called upon to sustain enormous and variable concentrated loads, machinery subject to severe shocks, tools performing special duties, and in all structures not met with in ordinary practice, an engineer should be free to adopt those requirements necessary to meet special features of design. Any steel manufacturer stands ready to furnish material of any grade from very soft to very hard. For these few and special cases the engineer and buyer must expect to pay the extra cost. It is to throw this extra cost on these special cases and on works of great magnitude and importance where it belongs, and not to increase the expense of all the ordinary and less important structures, that the writer suggests one main standard for ordinary bridge steel, wrought-iron and steel castings.

Mr. Garrison. F. Lynwood Garrison, Assoc. M. Am. Soc. C. E.—The objections to basic Bessemer steel which the author mentions are quite serious ones. The writer does not believe it is possible by this method of manufacture to obtain uniformly a product suitable for structural purposes. In the basic open-hearth furnace, the case is quite different, since it is possible to make quite as good steel by this method as in the ordinary or acid open-hearth furnace. It is not, however, possible to produce

good steel in a basic open-hearth furnace out of bad stock. Of course, the question as to what might be considered bad stock under the circumstances is one open to discussion, and the writer does not care to set up a standard for good or bad in a case of this kind; this is one of the secrets steel-makers must learn by experience. Mr. Garrison.

Exception is to be taken to the indiscriminate use of the word "crystalline" as applied to iron and steel. A crystalline structure is evidently one composed of crystals; a crystal is a solid body, bounded by plane surfaces which assume definite geometrical forms. How often has the author, in his extensive experience with structural steel, detected such crystals in the composition of a fractured surface? There is no intention to criticise the author's phraseology, as he is simply using a common expression, crystalline, applied to a glittering non-fibrous structure, in which, in 99 cases out of 100, it would be impossible to detect the slightest evidence of actual crystallization.

H. H. Campbell, M. Am. Soc. C. E.—Replying to Mr. Henning, the author would say that microscopical work is not among the ordinary systems of testing. The statement that open-hearth steel can be overheated is certainly not open to contradiction. That is a fact which has been known to every one in the business for 20 years, and which was perfectly well known to the author when this paper was presented. It was probably also known by Messrs. Hunt, White and Wailes. Unfortunately it is a fact which has nothing to do with the present subject of mysterious failures, for the fracture of an over-heated piece of steel is not a mysterious failure at all. It remains for Mr. Henning to first prove that these failures, mentioned by Mr. Hunt and others, are due solely to bad heat treatment, and then to prove that open-hearth steel would have failed under the same practice. A mere opinion or statement on this subject is of absolutely no importance when put against the positive facts presented by the authorities mentioned. As to the use of Bessemer steel for rails, it should be mentioned that rails do break much oftener than would be desired in the members of a bridge. The remarks on the shock tests are considered hypercritical. The blow at right angles to the stress seems a very practical application of vibration and "shock," as usually understood. Mr. Campbell.

The statement that it would be no hardship for the manufacturer to make different blooms and ingots for each thickness is absurd. It would be a great hardship and expense. The cost of steel in Germany has nothing to do with the question. The labor conditions of that country, as compared with ours, are known by almost every one. It is true that German manufacturers have not used a sliding scale; it is also true that American manufacturers have not used it, but that is hardly a sufficient argument why it may not be right, or why it may not be advisable, or even why recent developments have not made it almost necessary. The fact that German metallurgists have not yet

Mr. Campbell. adopted such a sliding scale had absolutely no weight with the author in determining the value of the innovation. But it may be well to record that foreign investigators have been holding international conferences for years to establish uniform and standard methods of testing, and that everything cannot be entirely perfect, else this trouble would not be undertaken. As to Professor Marten's experiments showing that soft steel does not offer greater resistance to shock than hard steel, the author will only say that he refuses to accept his conclusions. As to the comparison of steels of different makes, it may be said once for all that the works with which the author is connected makes Bessemer structural material to an extent exceeded by only two or three works in the country; that it makes acid open-hearth steel to an extent equaled by only one works in the country, and that it makes basic open-hearth steel to an extent equaled by only one works in the country. It may reasonably be assumed that the opinions expressed in the paper are unbiased, and that their correctness is limited only by the ability of the author to deduce correct conclusions from ample premises. From this platform of experience, the author would say that Mr. Henning's statement of the inferiority of low acid open-hearth steel is not correct.

Replying to Mr. Lewis, it may be said that there is nothing to prevent an acid open-hearth works from making low-phosphorus material, even when it does not have basic material. The difference in cost of the raw material is not excessive; there is at least one such works now making such material for the open market. The fact that low-phosphorus basic steel will temper, whatever that word means, is indisputable. It is also true that the softest product of any iron or steel process is very materially affected by heating and quenching, but the author has never discovered what this fact has to do with the use of material in a railroad bridge which is not calculated to withstand a conflagration followed by a flood. The statement that the automatic device gives erroneous readings for the elastic limit at moderately high speeds is one of the most important facts or opinions in the entire discussion, and is worthy of careful consideration. The phrase "elastic limit" has become an arbitrary term as part of a trade nomenclature. It denotes the place where the beam drops; and this is the universal meaning in American steel works. A few investigators are trying to introduce an autographic device, and Mr. Lewis now declares that this is just as arbitrary as the present method. The criticism of the low elastic ratios in the specifications is rather unjust. The 47% mentioned is on a 1¼-in. plate of a steel which will give 70 000 to 80 000 lbs. ultimate strength and 56 or 58% elastic ratio on a plate or angle of ordinary thickness. All the test pieces cited in the main body of the paper are on usual thicknesses, while all the low elastic ratios given in the specifications will be explained by the thickness of the member and by high ultimate strength.

Mr. Campbell.

Replying to Mr. Wagner on the advisability of a lower limit for phosphorus, the author would consider this a very objectionable innovation. It might result in the rejection of many heats and great loss to the manufacturer, who might often fail to keep between the lower and the upper limit. Such a change would therefore be warranted only by facts showing the bad quality of low phosphorus steel, and such facts are conspicuously absent. The phosphorus in heat No. 10 168 in Table No. 6 is 0.013%, which is probably as low as can be found in any acid steel ever made; but it is hardly probable that any question will be raised about the quality of the metal.

The call from Mr. Lund for a strong steel for building purposes is met by Class IX. The requirements are purposely made very severe, as every precaution must be taken to insure toughness. The suggestion that alloys be devised that will resist corrosion opens up a field which has been practically unexplored. It seems rather unlikely that much can be done in this direction, for the aim of the steel-maker should be to produce the maximum of toughness and strength, while it is left for others to devise some process of coating or painting by which the metal is preserved from destruction. An alloy of iron may be discovered which will not be subject to corrosion, but it is doubtful if it would come under the name of structural steel.

The remarks of Mr. Hunt on the inconsistency of condemning the system of "preliminary tests," and then advocating its use in steel castings, are neither unexpected nor entirely undeserved. The explanation is that the author is not a crank, and that he is willing to use an unsatisfactory system when it will save great expense and delay. Moreover, it must be considered that steel castings do not go through the process of rolling, so that a sample bar may more fairly be used as an index of quality of the metal than in the case of other structural material when it must represent sections of all thicknesses, some of which may have been either overheated or cold finished. The stipulation that basic steel shall not show as high a percentage of phosphorus as acid steel must not be misunderstood. It does not mean that a proper basic slag will inevitably eliminate phosphorus to a low proportion, for the resulting percentage is dependent on the initial content, as well as on the nature of the slag. Almost any stock may be purified to a certain point by suitable slag, but this slag must vary, both in quantity and quality, with the work to be done. A content of 0.08% of phosphorus in basic steel may, therefore, be a result of good practice upon very phosphoritic metal. Neither does this provision concede that phosphorus is more harmful in basic than in acid steel, for there is no proof either that it is or is not. The only point involved is the thoroughly practical and business-like proposition that it is well to require lower phosphorus where it can be easily and economically obtained.

Mr. Campbell. Replying to Mr. Waddell, the author would say that the questions asked are rather beyond the scope of the paper. The terms "soft," "medium" and "hard" are relative and must always remain so, and the nomenclature is entirely unimportant. The decision as to the proper ultimate strength for different purposes is not so secondary a matter, but no dogmatic assertion by the author could possibly settle the question. There will always be differences of opinion, and the manufacturer is willing to make what the engineer thinks best. An opinion is expressed in favor of softer metal, but this is not done to give an advantage to the manufacturer, it being hoped that the paper is not open to the criticism of self-interest. It is true that a softer steel can be made a shade more easily by the basic process than a metal of slightly higher strength, but the greatest economy that could be introduced would be a uniform set of specifications among engineers, so that surplus stock could be applied to other contracts.

The remarks of Messrs. Webster, Howe, Hartshorne and Greiner deal for the most part with matters of opinion on which all metallurgists cannot be expected to agree. The last word is not necessarily any better than the first, and there is no occasion to reiterate any statements previously made. It may be well to say, however, that the author was aware of the paper by Professor Tetmajer, but that he is also aware of a book by Dr. Wedding which gives illustrations of the basic Bessemer practice in Germany a few years ago, and the amount of re-phosphorization and the final content of phosphorus would condemn the steel for the most common purposes. The author is also in possession of other information as to the irregularity of basic Bessemer steel, but the publication of such facts is a very unpleasant occupation. Suffice it to say that no succession of good results from any particular works can wholly justify the general acceptance of basic Bessemer steel as structural material. On the other hand, the author does not suppose that his condemnation can keep this metal out of the market if manufacturers prove, by long experience, that the old and formidable difficulties have been conquered.

The matter of elastic limit, referred to at length by Mr. Webster, has been discussed in replying to Mr. Lewis, and reference was made to the statement that the new method of determination, by the autographic device, is as arbitrary as the drop of the beam. The present method is thoroughly understood, and all contracts and calculations are based on a certain way of finding a certain point. If some other method is to be used, then the steel-maker must be notified beforehand. The meaning of a specification, as now written, is that the elastic limit is taken by the drop of the beam, and any attempt to introduce a new meaning after the agreement is signed is an alteration of the contract. All the elastic limits in the paper under discussion were determined in the regular way, the bars being tested as all structural material has

been tested at the Pennsylvania Steel Works. Neither the accuracy of the machine nor the methods employed have ever been called in question by any inspector, and Mr. Lewis, Mr. Cunningham and Mr. Webster himself have been among the number who have accepted the results. This fact does not prevent Mr. Webster from advocating any new method of testing, but it certainly sets the seal of his approval upon the statement that the system herein employed is the currently accepted method in common use. Mr. Campbell.

Mr. Goldmark's remarks on the limits of tensile strength refer to small test pieces of uniform size, which can be rolled under uniform conditions. This is a different matter from the present practice of cutting strips from sections of many different sizes.

The remarks of Mr. Seaman on the variation in elastic limit are very important to the engineer, but they do not state anything which was unknown to the author. The specifications are not made to favor anybody or to use up defective material. They are drawn to legally recognize certain actual and existing facts and laws, whereby a thick piece of metal does give a lower elastic ratio than a thin piece when they are rolled under the same conditions. The fact may be new to some engineers and it may be unpleasant, but it is a fact nevertheless.

Mr. Garrison's remarks on basic open-hearth steel are very ambiguous. He states that good steel cannot be made from "bad stock," but qualifies this by saying that he will not attempt to define "bad stock." There is no original sin in any special grade of metal, the grade of badness depending almost entirely on the percentage of phosphorus and sulphur. Given a bath with an average content of 0.08% phosphorus, and it is perfectly immaterial whether this has been produced by the use of one kind of metal holding exactly 0.08% phosphorus, or whether it has been made by a mixture of a large amount of metal containing 0.03% and a small amount containing 1.00 per cent. In the same way on the basic hearth, it matters very little whether a content of 0.05% of phosphorus has been produced by the use of an iron containing 0.10%, together with a rather silicious slag, or whether it has been made from an iron containing 1.00% under the action of a basic slag. Prejudice or opinion has nothing to do with the case. Thousands of tons of good steel are being produced every month out of what always has been called bad stock. The time has gone by to say that this cannot be done. The time has come to see and believe.

In this connection, it may be well to remark that many of the published statements concerning basic steel are wrong, and that some of these statements have been made by those who should know better. A content of 0.08% of phosphorus in basic steel does not necessarily denote bad metallurgical work. It may denote very good practice on bad stock, and redound much more to the credit of the metallurgist than a content of 0.05% when made from a purer metal.

Mr. Campbell. The word "crystallize," to which Mr. Garrison takes exception, might be made the subject of a long dissertation. It is very doubtful whether steel can undergo molecular rearrangement when the metal is at the ordinary temperature of the atmosphere, although it may, by certain conditions of shock and stress, be internally disrupted, so that it shows innumerable planes of cleavage. This structure is called crystalline. It matters not whether the term is or is not correct, for it is in universal use, like "elastic limit," as part of a trade nomenclature and is so used in the paper. It may be in order, moreover, to point out to Mr. Garrison that it is very difficult to be always logically right. An ingot of steel when cooling from a liquid to a solid form arranges itself in coarse crystals. Subsequent heating and rolling reduce the size of these crystals and distort them and weld them to one another, but it is doubtful if they are ever completely destroyed. If this is so, and the author believes he is only stating the commonly accepted theories, how can it be said by Mr. Garrison that "in 99 cases out of 100, it would be impossible to detect the slightest evidence of actual crystallization." Bearing in mind the possibilities of microscopical examination and ultimate chemical analysis, this is a statement which is rather bold, to say the least. Such a comprehensive investigation is not usual, but Mr. Garrison would invite it by his challenge to come down to fundamental facts.

The plan of Mr. Deans, reducing the number of standard grades, is very attractive. There are, however, certain cases where an exceptionally strong steel is indicated, and such cases must be provided for in a complete schedule. Moreover there are some cases where the very best and most reliable metal is obligatory, while there are times when a common metal, like Classes XI and XII, will answer every purpose, and at much less cost. The author would not attempt to limit the range of material at the disposal of the engineer, but has simply tried to give the physical qualities that can be expected from the different kinds of steel. He has not touched upon the question of wrought iron and is therefore at a loss to understand the remarks of Mr. Deans as to the specifications on this material.

The author is in receipt of a communication from Mr. George Bartol, Superintendent of the Otis Steel Company, Cleveland, Ohio, who states that absence in Europe has prevented his taking part in the discussion. He takes exceptions to the conclusions on segregation, being of the opinion that it is a more serious matter than is shown by the records given, but aside from this, says that he can endorse nearly all that is written in the paper. Hs also hopes that it will "aid in bringing engineers to more rational methods of inspecting and specifying for material, a change which we both know from personal experience is sadly needed." This corroboration of the main points of the paper by Mr. Bartol is worthy of careful consideration as coming from a practical and competing manufacturer.